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LOCALIZED AND GLOBAL APPROACHES FOR TILED WINDOW MANAGEMENT BY: JF CHEN, JS GREENSTEIN

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Localized and Global Approaches for Tiled Window Management

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Abstract

Window management systems provide a very flexible environment for the display of raster-based information. Some systems permit windows to overlap, while others require that windows be tiled. Some systems automatically determine the location and size of a new window, while others require the user to locate and size the window. This research compared two approaches to window management commonly used in tiled window systems. The first, termed the localized approach, creates space for a new or enlarged window by taking space from adjacent windows in the same row. Space is taken from nonadjacent windows only when adjacent windows do not have enough space to meet the needs of the new or enlarged window. The second approach, termed the global approach, creates space for a new or enlarged window by taking equal amounts of space from all the other windows in the same row. The objective of this research was to determine the relative efficiencies of these two approaches when used under each of four decision making scenarios. The results of a controlled, behavioral study of human performance suggest that one, or the other, of the two window management approaches is appropriate depending on: the amount of space available for information display, the variability in the sizes of the data sets that are to be displayed, and the interdependency among these data sets.

[illegible]

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CHAPTER I

INTRODUCTION

[illegible] the past several years there have been significant [illegible] in the design of human-computer interfaces. Central to many of the new techniques for interface design is the management of display windows through which computer-based information may be viewed. Window management systems allow the user of a computer-generated display to simultaneously view and interact with multiple sources of information. Thus, [illegible] the video display unit may achieve functionality equivalent to [illegible] workstation equipped with a much more costly variety of display hardware.

A window management system can be characterized by the set of design features it provides for window management. For example, some systems permit windows to overlap, while others require that windows be tiled. Some systems automatically determine the location and size of a new window, while others require the user to locate and size the window.

This research compares two approaches to window management commonly used in tiled window systems. The first, termed the localized approach, creates space for a new or enlarged window by taking space from adjacent windows in the same row. When the adjacent windows do not have enough space to meet the needs of the new or enlarged window, space is also taken from the next most adjacent window. The second approach, termed the global approach, creates space for a new or enlarged window by taking [illegible] amount of space from all the other windows in the same row. [illegible] research is to determine the relative [illegible]

of these two approaches when used under each of four [illegible] scenarios. A controlled behavioral study of human decision making performance using the [illegible] and [illegible] approaches [illegible] tent was designed to permit comparison of the two approaches. The results of this study will be used to suggest several guidelines for the selection of a window management approach as a function of the amount of space available for information display, the variability in the size of the data sets that are to be displayed, and the interdependencies among these data sets.

CHAPTER II

LITERATURE REVIEW

The human factors issues derived from a literature review of window based human computer interfaces can be divided into seven categories:

1. the benefits of using multiple windows
2. window categories
3. tiled windows vs. overlapping windows
4. user control vs. system control
5. localized vs. global window management
6. window management command syntax
7. window management input devices.

The Benefits of Using Multiple Windows

A window management system gives the user access to the full power of a multitasking operating system by allowing several interactive applications to run at once (Goodfellow, 1986). Without a window manager the user is forced to run a single interactive application and is able to use multitasking only for batch programs.

Window managers can serve at least seven functions (Card, Pavel and Farrell, 1984):

1. They allow relatively rapid access to more information than would be accessible with a single frame of information using the same screen size.
2. They permit access to multiple sources of information.
3. They can be used to combine multiple sources of information.
4. They can be used to control multiple programs.

5. They can be used to provide the user easy access to information that may be useful in the near future. For example, pop-up windows containing menus of commands or a clock window giving the time can be displayed.

6. They serve as an indication of command context and active forms. When the display cursor is in a given window, commands take on a specific meaning or that window becomes active. This allows the command language to be simpler and more modular.

7. They can be used to display multiple representations for the same task. This can permit the user to perform a sequence of actions using the representation easiest to use at each point in the sequence.

Bury, Davies, and Darnell (1985) conducted an experiment to test the hypothesis that the user can gain benefits from multiple windows in a task which requires the display of supplemental information relevant to the user's primary task. Although users of the windowed environment spent additional time getting windows onto the screen and arranging them in a usable layout, their performance was more accurate than that of users in the non-windowed environment.

Bury et al. (1985) suggest that users can also benefit from multiple windows in the following tasks:

1. tasks in which users monitor system changes in a secondary window while performing a task in a primary window;

2. tasks in which specific locations within more than one application need to be specified.

Window Categories

Card et al. (1986) stated that current designs for window management systems can be broken down into approximately four categories: simple "TTY" windows, time-multiplexed windows, space-multiplexed windows and non-homogeneous windows. Simple "TTY" windows imitate the mechanical flow of paper in a teletype machine. Time-multiplexed windows include scrollable windows and frame-at-a-time systems.

Space multiplexed windows can be grouped according to the spa-tial dimensions they employ. Within these groups, space-multiplexed windows may be further classified as independent (displaying unrelated information) or split (displaying subsets of closely related information). A one dimensional window is a screen divided either vertically or horizontally into a number of separate parts. Two dimensional windows are tiled windows and two-and-a-half dimensional windows are overlapping windows.

Non-homogeneous windows include those in which the level of the displayed information may change within or across windows. Icons, bifocal windows, fish-eye windows, and zooming windows are techniques for accomplishing this.

Icons are very small windows, generally represented on the screen by a small symbolic picture of some sort. An icon may be selected and expanded into a full-size window. Icons are a means for keeping reminders of a large amount of information on the screen without taking up much space.

Bifocal windows include those windows in which hierarchical information is displayed in full detail in the center. Related information is displayed on the periphery in just enough detail to recognize it. Thus, the user always has detailed display of some item of interest and non-detailed display of contextually related items.

In optical fish-eye windows, information is compressed in the window like the image of a convex mirror. In logical fish-eye windows, information detail displayed on the screen may be reduced according to its logical distance from some focal point. For example, a program listing may be completely displayed for one arm of a conditional

statement [illegible] interest in [illegible]

devoted to each of the other arms of the conditional statement.

In zooming windows, data in a window or the window [illegible] gets larger or smaller in the manner of a zooming camera lens. This effect may involve changing type fonts, suppressing parts of the diagram, or even distorting parts that are most important.

Cohen, Smith, and Iverson (1986) reported that four different kinds of tiled window organizations have been built:

1. Single column--Windows are lined up vertically in a single column.

2. Multicolumn--The screen is divided into multiple columns, and windows are lined up vertically in each column.

3. Hierarchical--The screen is divided either vertically or horizontally into partitions, and the partition is then recursively divided into subpartitions. Windows correspond to the final set of undivided partitions. Each partition corresponds to a node in a hierarchy, with windows at the leaves.

4. Nonhierarchical--Any rectangular tiling can appear in the system.

Tiled Windows vs. Overlapping Windows

A tiled window system is defined as one in which any open window is always fully visible; windows are not allowed to overlap. An overlapping window system is defined as one in which the user can manage a window's location and size in any way desired.

Goodfellow (1986) noted that tiled windows and overlapping windows each have advantages. The advantages of tiled windows include:

1. Since no window is obscured, the user never has to rearrange the screen to see something that has been buried accidentally, as is common with the overlapping model.

2. The screen is better utilized, since it is completely covered with windows.

3. The architecture is easy to implement.

4. The window manager [illegible] tions are responsi[illegible] dow manager does [illegible] the windows

The advantages of overla[illegible]

1. A new window is [illegible] approach than wit[illegible]

2. With the tiled mode[illegible] iconized when a new win[illegible] rearrange these i[illegible] the user [illegible] identify icons with thei[illegible] avoided with the overlapping mode[illegible] need to be moved out or iconized

3. Overlapping windows permit the user to [illegible] a window wherever he wants, unconstrained by the position and size of other windows

4. More windows can be displayed at once using overlapping windows.

Cohen et al. (1986) reported that users of the desktop model (which allows windows to overlap each other like sheets of paper piled up on a physical desk) pay a price for its flexibility, especially when large numbers of windows need to be accommodated. The desktop can become messy, forcing the user to constantly locate and rearrange windows. Overlapping windows may be most useful for systems using small screens or for applications that use only a few windows over a long period of time. Compared with overlapping windows, tiled systems which allow the user to control the tiling are safe (users do not need to worry about what has been buried accidentally) but can require enough work of the user to become frustrating. A tiled system which automatically retiles the screen based on the user's action can relieve the user of window management tasks, but it may locate and size windows inappropriately, requiring the user to adjust the layout manually. It is possible to place constraints on the relocation and resizing of the windows.

however. The user should [illegible] the constraints help to ensure that the right windows are on the screen in the right place with the right size. Tiled windows may be especially useful for applications that generate large numbers of small, short-lived windows.

Bly and Rosenberg (1986) conducted an experiment to compare tiled windows with overlapping windows and reported that tasks which require much more window manipulation (tasks in which users must frequently arrange the windows and make the necessary text visible within the borders of the windows, either by scrolling or changing the window sizes) can be carried out more quickly using overlapping windows, while tasks which require little window manipulation can be carried out more quickly with tiled windows. If users are inexperienced in the use of overlapping windows, tiled windows are better for both kinds of tasks. The authors suggest the possibility that for a user equally proficient with overlapping and tiled window systems, tiled windows may be better in both situations. Paradoxically, however, 19 of the 22 subjects studied preferred overlapping windows to tiled windows.

User Control vs. System Control

Bury et al. (1985) reported that one of the most significant ways in which window management systems differ is in whether the windows are under user or system control. Some of the most effective uses of multiple windows have been in systems in which the configuration of the windows is entirely under system control. System controlled windows offer many of the advantages of windows, while avoiding many of their disadvantages. In many cases, the window management system can be given the intelligence to decide the best location and size for a window.

[illegible] the user of these [illegible] vary in the amount of user control they allow depending on the type of window. Menu, message and help windows are often less modifiable than work windows. Some systems give the user no control over the placement of menu windows. Other systems allow the user to specify the location where the window will be opened but nothing else. Still others allow the user to move the window around after it has been opened. In most cases, once a selection from the menu list is made, the window is automatically removed. Still other systems make a distinction between types of work windows, giving certain types of work windows full customizability, while limiting the function of others.

Localized and Global Approaches for Window Management

Cohen et al. (1986) stated that tiled window management systems differ widely in their approaches to resizing and opening a window. When a window is resized in Andrew and RTL/RTL (two of the several different window management system implementations that have been reported in the literature), effects are local and manual (only the adjacent window is given or gives up space and the amount of space given or taken is controlled by the user.) In Cedar and RTL/CRTL, effects are global and automatic (all the other windows are given or give up space with the amounts of space given or taken controlled by the system). In Gosling's EMACS system the effect is as local as possible. If the adjacent window does not have enough space, space is taken from the next most adjacent window. In the RTL/RTL system, after specifying the window to be opened, the user locates it at the edge of a tile and then pulls on the edge to make space for it. Both Cedar and Microsoft Windows support

[illegible] that takes space away from other windows proportionately. Microsoft Windows [illegible] the bottom window. Microsoft Windows also supports two manual placement techniques. In one, the window is simply located at the edge of a tile, and space for the new window is taken away equally from the windows on both sides of it. Microsoft Windows also allows the user to locate a window on top of an existing window, completely replacing that window. Andrew supports both manual and automatic placement. For automatic placement, it finds a window large enough to be split so that even after space for the new window is taken away from it, it is still larger than its size constraints require. In manual placement the specified location is used to find a location in the window hierarchy, and this determines the actual placement.

Window management systems also differ greatly in their approaches to closing a window as a result of resizing or opening another window. In systems where resizing has local effects, enlarging a window takes space from an adjacent window. When the adjacent window becomes too small, either enlargement is prohibited (e.g., Gosling's EMACS) or the adjacent window is automatically closed (e.g., Andrew and RTL/RTL). Andrew may also close a window when another window is opened. Neither Cedar nor Microsoft Windows automatically closes windows. Cedar will not allow a window to be enlarged if this will force all the other windows in its column to be shrunk below their minimums, but it will open a new window, even if this shrinks the remaining windows below their minimums. Microsoft Windows will not open a window if there is no space available for it. RTL/RTL has a variety of options for treating automatic closure. If the user specifies explicit closure, [illegible]

[illegible] will [illegible] limits are placed on enlargement, and windows that are too large are not allowed to be opened until the user closes other windows. If the user chooses to permit automatic window closure (e.g. RTL CRTL), then the windows to be closed may be required to be local so that only windows adjacent to the opened window will be closed. Alternatively, windows will be closed on the basis of age and priority.

Window Management Command Syntax

Bury et al. (1985) stated that different systems may have semantically identical command interfaces, but be radically different in their command syntax. Some systems adopt an action/object command structure while other systems adopt an object/action command structure. It is easier to construct effective user prompts for a system which uses an action/object syntax structure. This is because effective prompts require knowledge of the user's intentions, and the user's intentions can be deduced to a greater extent with knowledge of the action than with knowledge of the object. On the other hand, the object/action syntax structure usually results in a system with fewer modes and this is generally regarded as desirable.

Window Management Input Device

Bury et al. (1985) noted that different systems might require users to take the following actions to issue commands:

1. Point at and select actions and objects with a mouse.
2. Point at and select with cursor keys.
3. Type in commands (for instance, "Move window 1 [illegible]").
4. Invoke commands via function keys.
5. Issue commands [illegible].

In additi[illegible] ... [illegible] ... system might be represented to the user entirely with words or at least partly with graphic icons. The basic syntax of commands might be the same in all these systems, but the command mechanisms might be very different.

CHAPTER III

RESEARCH OBJECTIVE AND HYPOTHESES

The literature review makes it clear that the window management system provides a very flexible environment for the display of computer-based information. Although many window management systems have been developed and a number of researchers are pursuing the development of even more powerful systems (Hopgood, Duce, Fielding, Robinson, and Williams, 1986), only two empirical investigations of human performance with such systems appear to have been reported in the open literature: Bly and Rosenberg (1986), investigating tiled windows vs. overlapping windows, and Bury et al. (1985), investigating the benefits of multiple windows. Since the principal reason for using window management systems is to gain the benefits of a better human-computer interface, it is important for system designers to know, for example, in which situations the localized approach for resizing and opening tiled windows is better than the global approach and in which situations system control of window management is better than user control. Such information would permit designers to implement the window management system appropriate for a given situation.

Because users of tiled window management systems may need to spend substantial amounts of time arranging windows into configurations suitable to perform tasks, particularly if windows become too small to fully display the information associated with them, it is worth investigating the effects of localized and global approaches for tiled window management on overall task performance. The objective of this research is to

determine the relative efficiency of these two approaches [illegible] under various decision making scenarios.

As noted in the preceding literature review, current window management systems differ in their approaches to opening and resizing a window. In some systems the effect of opening and resizing a new window on the existing windows is localized, with space created for a new or enlarged window by taking space from adjacent windows. When the adjacent windows do not have enough space to meet the needs of the new or enlarged window, space is also taken from the next most adjacent windows. In other systems the effect is global, with space created for a new or enlarged window by taking space from all the other windows in the same row or column of the display. The effects of these two approaches on the layout of a display are illustrated in Figures 1, 2, and 3.

Three hypotheses are proposed regarding the effects of these two approaches on the amount of time the user must devote to window management. In stating these hypotheses, it is assumed that a maximum of M rows of windows are permitted on the display. The mean number of data sets that can be displayed in their entirety within the spatial confines of each of these M rows is denoted by N. Thus, on average, the total area available on the video display is sufficient to permit the simultaneous display of MxN data sets in their entirety. When less than MxN data sets are displayed on the video display at once, it is likely that the window allocated to each of the displayed data sets will be large enough to display the full contents of the data set. When more than MxN data sets are displayed on the video display at once, it becomes more likely that the windows allocated to one or more of the displayed data

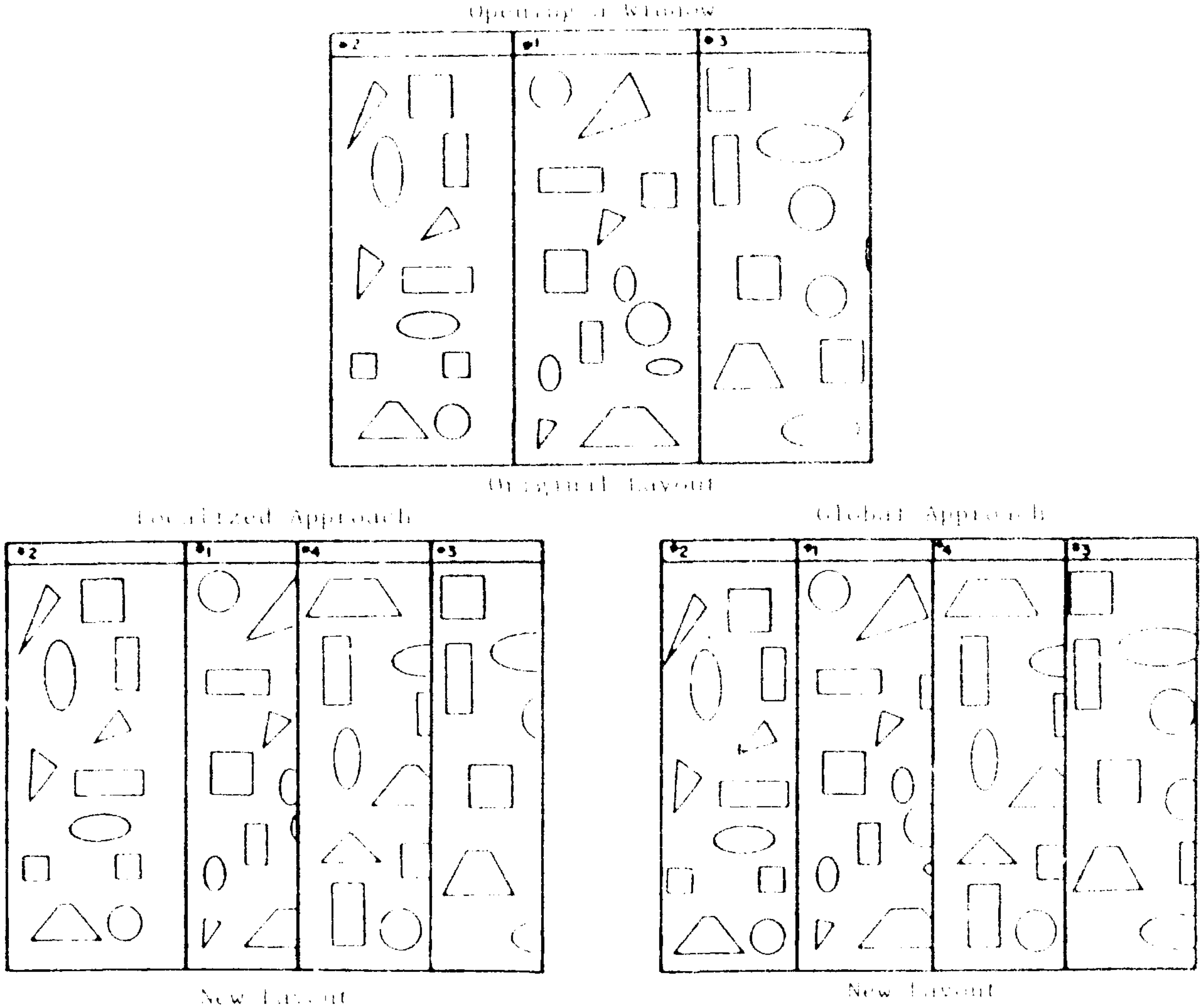


Figure 1   Localized Approach vs. Global Approach in Opening a Window (a)

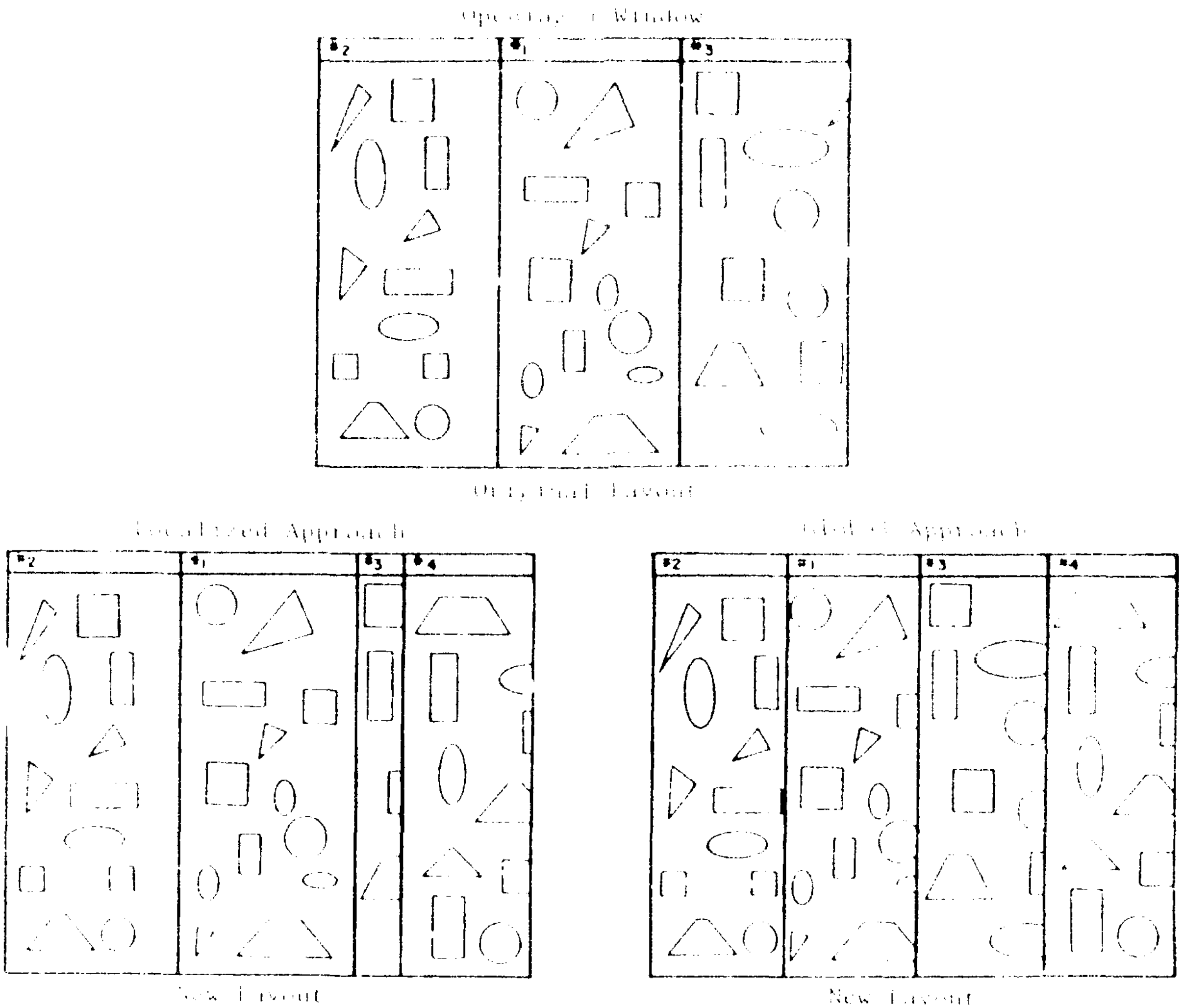


Figure 2 Localized Approach vs Global Approach in Opening a Window (b)

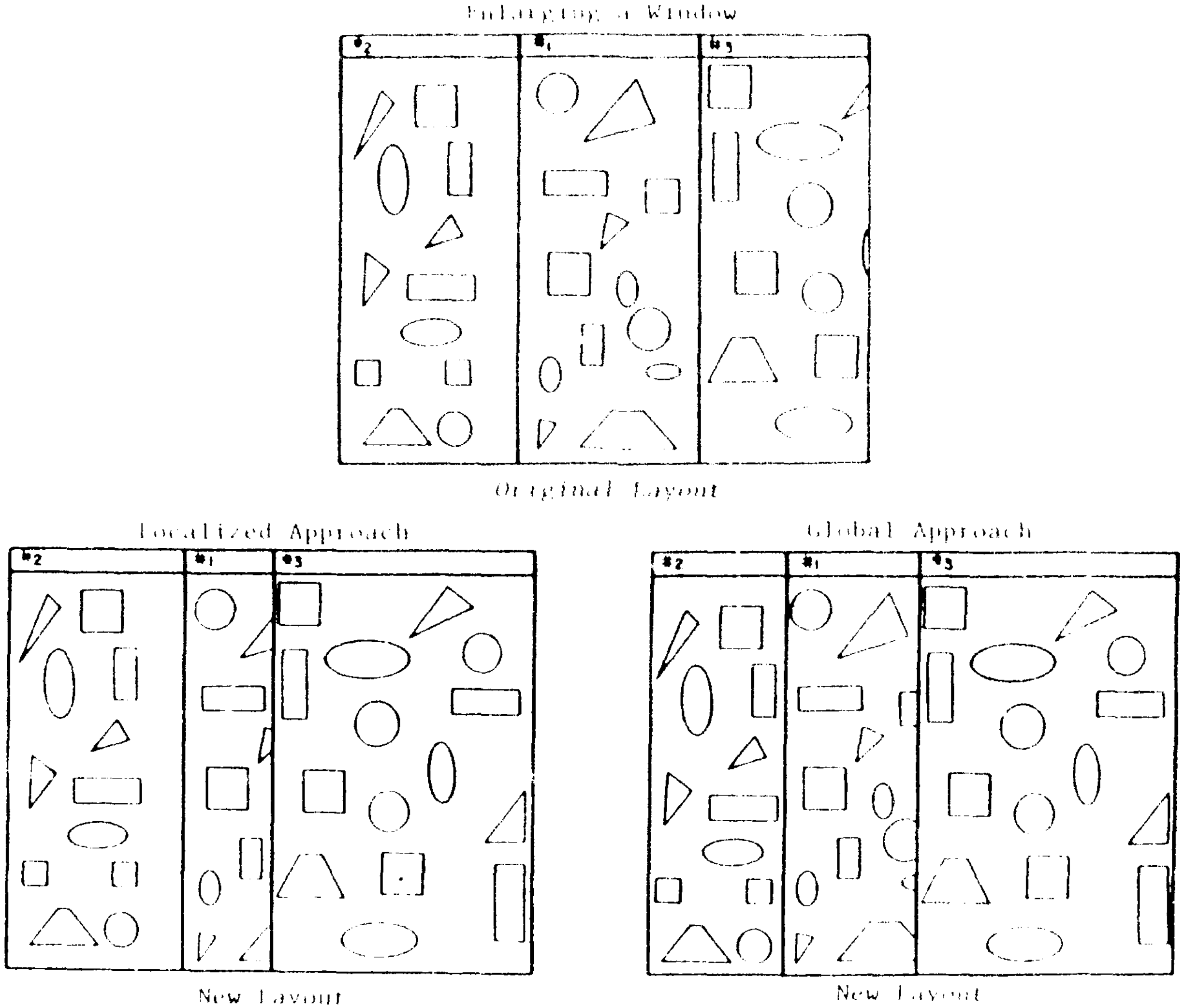


Figure 3 Localized Approach vs. Global Approach in Enlarging a Window

sets will not be large enough to display the full contents of the data set.

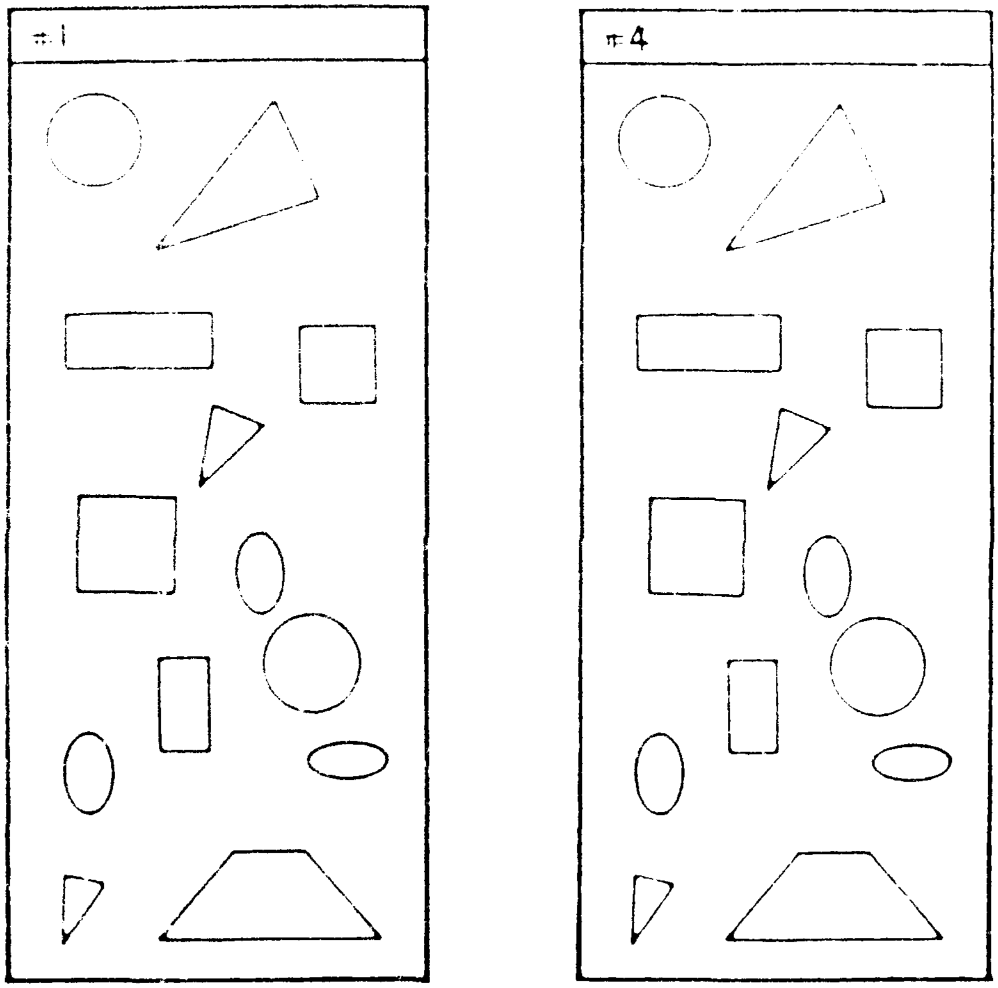
Hypothesis 1

If there are less than MxN windows on the display and the sizes of the different data sets required to perform a task are approximately equal, then a system employing a global approach to window management will be more efficient than an otherwise equivalent system employing a localized approach. (Figure 4 illustrates two data sets that are of equal size.)

The basis for this hypothesis is as follows: When there are less than MxN windows on the display and the data sets displayed in these windows are approximately equal in size, it is likely that each of the windows contains space in excess of that required to display the full contents of the associated data set. Thus, if an existing window needs to be enlarged or a new window needs to be opened, the small amount of space that will be taken from each window to accomplish this operation under the global approach may leave these windows sufficiently large to continue display of the full associated data sets. Under the localized approach, however, space will be taken from only one or two windows. The large amount of space that each of these windows must give up may leave these windows too small to continue display of the full associated data set. Thus, enlarging an existing window or opening a new window may have to be followed by additional window enlarging operations.

Hypothesis 2

If there are less than MxN windows on the display, the sizes of the different data sets required to perform a task vary greatly, and the



[illegible] Low Variability of Data Set [illegible]

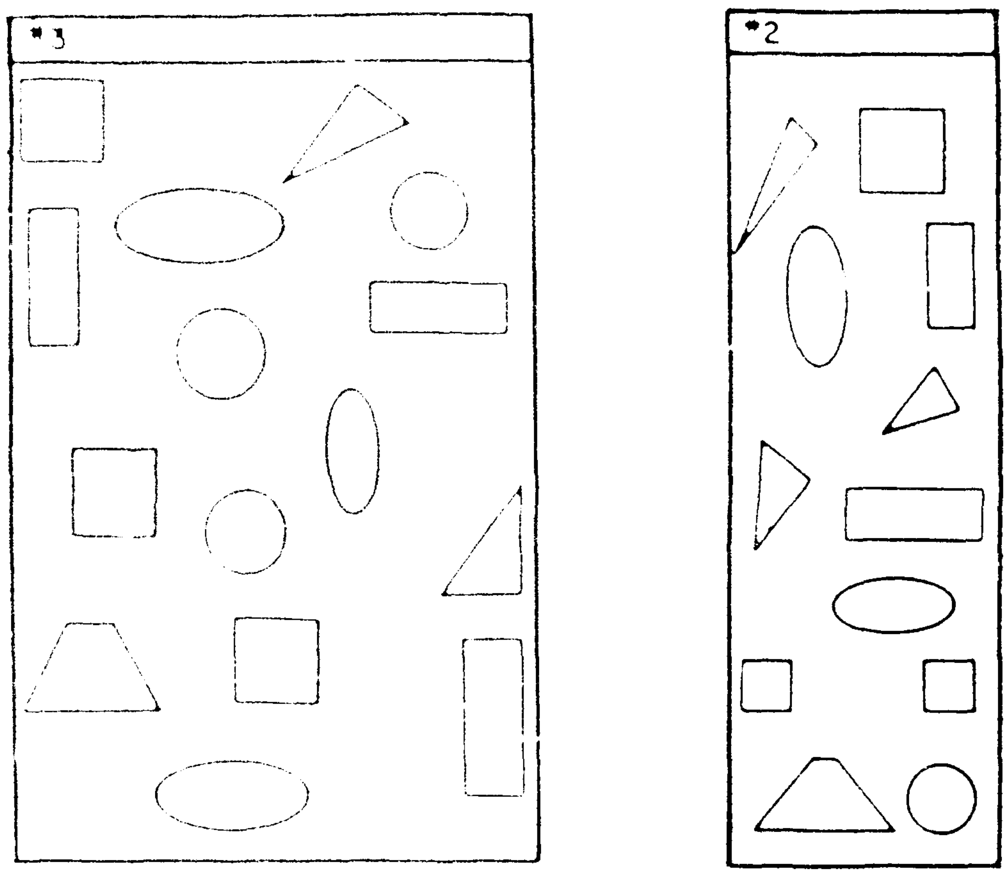
data sets are highly interdependent, then a system employing a localized approach to window management will be more efficient than an otherwise equivalent system employing a global approach. Figure [illegible] illustrates two data sets that vary greatly in size.

The basis for this hypothesis is as follows: When there are less than MxN windows on the display and the data sets displayed in these windows vary greatly in size, it is likely that some windows contain a great deal more space than that required to display their contents, while other windows do not contain much excess space. If the data sets required to perform a task are highly interdependent, the full contents of several of these data sets may need to be displayed simultaneously to permit performance of the task. If an existing window needs to be enlarged or a new window needs to be opened, the localized approach permits the user to take space only from those windows with sufficient excess space to meet the needs of the operation. Under the global approach, more windows would be affected by the operation, increasing the likelihood that windows without much excess space would be reduced below the size needed to view their full contents. This, in turn, would increase the likelihood that additional enlarging operations will be required.

<u>Hypothesis 3</u>

If there are MxN or more windows on the display and the data sets required to perform a task are highly interdependent, then a system employing a localized approach to window management will be more efficient than an otherwise equivalent system employing a global approach.

The basis for this hypothesis is as follows: When there are MxN or more windows on the display at once, it is likely that the [illegible]



#3
#2

[illegible] required to display the full contents of the associated data set. If the data sets required to perform a task are highly interdependent, the full contents of several of these data sets may have to be displayed simultaneously to permit performance of the task. Thus, if an existing window needs to be enlarged or a new window needs to be opened, the localized approach will reduce only one or two windows below the size needed to view their full contents. Only if the data sets contained in these windows are necessary to complete the task will any additional enlarging operations be necessary. Under the global approach, however, several windows will be reduced below the size needed to view their full contents, increasing the likelihood that additional enlarging operations will be required.

CHAPTER IV

EXPERIMENTAL PLAN

An experiment was designed to test the relative efficiencies of the localized and global approaches to tiled window management when used under each of four decision making scenarios. In this experiment the maximum number of rows permitted on the display (M) was fixed at two, while the mean number of data sets that can be fully displayed within each of these rows (N) was fixed at five.

Subjects

Eight Clemson University students participated in this study. Volunteers were screened for corrected 20/20 vision at a distance of 67 cm. They were paid $30 for the time spent in the experiment (7 to 8 hours).

Apparatus

The hardware configuration consisted of a Tandy 3000 HD personal computer with keyboard interfaced to a Tandy VM-3 monochrome text monitor and an NEC Multisync JC-1401P3A color graphics monitor. Software was written to produce a tiled window system manager capable of opening, enlarging, and reopening windows in each of at most two rows using either of the localized or global approaches to window management. The software was also designed to permit automatic closing of existing windows when opening, enlarging, or reopening another window reduces the amount of space available to the existing window below a specified minimum.

Task

The task environment consisted of a number of data sets, each containing a variety of two-dimensional graphic objects (i.e., circles, ellipses, squares, rectangles, parallelograms, and trapezoids). Participants in the study were asked to determine specific facts from these data sets using the window management system (e.g., What is the total number of squares contained in data sets b, c, and d?). The window management system could be used to open or reopen a specified window at a specified location. It could also be used to enlarge a specified window through movement of the left or right window boundaries to specified locations. All textual input and output (questions to be answered by the participant, window management commands entered by the participant, feedback directed to the participant, and answers entered by the participant) were directed to the monochrome text monitor (see Figure 6). All data sets were displayed in a graphical windowed environment on the graphics monitor in white on a black background. Figure 7 illustrates this environment. (Asterisks denote the endpoints of data sets. The DATA SET MENU contains icons of data sets that have yet to be displayed. The HIDDEN DATA SETS menu contains icons of data sets that have been removed from the display to make room for other data sets.)

Independent Variables

Three independent variables were investigated. The first, window management approach, was tested at two levels: localized and global. The second and third independent variables together characterized four different decision making environments in which windowing systems might be employed. The second independent variable, variability of data set size, was tested at two levels: low and high. In the low variability

```
 ''''''''''''''''''''''''''''''''''''''''''
 : ENTER 'd' TO DISPLAY A DATA SET      :
 : ENTER 'e' TO ENLARGE A WINDOW        :
 : ENTER 'r' TO REDISPLAY A DATA SET    :
 : ENTER 'a' TO GIVE AN ANSWER          :
 ''''''''''''''''''''''''''''''''''''''''''
QUESTION 26
What is the total number of circles and squares
contained in data sets h and k?
>a
GIVE YOUR ANSWER
>7
This answer is correct.  Enter any key to continue
```

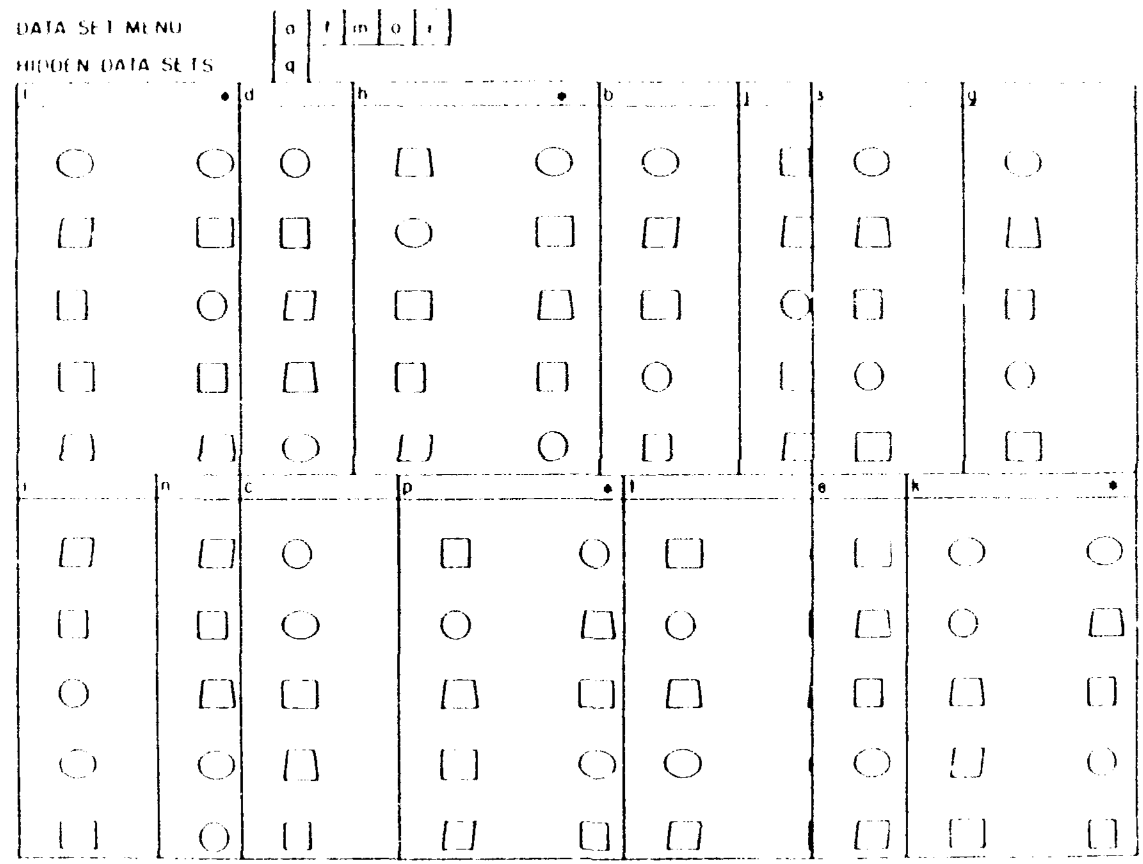


Figure   Windowed Data Sets Displayed on the Graphical Display

case all the data sets required equal amounts of space to display their contents (this amount of space was an area with height equal to one half the display height and width equal to one-fifth the display width). In the high variability case the mean amount of space required to display the full contents of a data set was the same as in the low variability case, but some data sets required little space for complete display, while others required much larger amounts of space (data set widths were normally distributed with a standard deviation equal to one-fourth of the mean data set width). The third independent variable, interdependency of data sets, was tested at two levels: low and high. In the low interdependency case participants were required to retrieve information from two data sets at a time to determine facts (e.g., What is the difference between the total number of trapezoids and rectangles contained in data set g and the total number of circles and parallelograms contained in data set k?). In the high interdependency case two to four data sets needed to be accessed to determine facts (e.g., What is the total number of squares contained in data sets e, o, r, and t?). The task sets employed in the low and high data set interdependency treatment conditions are included as Appendix F.

Experimental Design

There were eight treatment conditions resulting from the crossing of two window management approaches, two levels of data set size variability, and two levels of data set interdependency. A completely within-subject experimental design was used (see Figure 8).

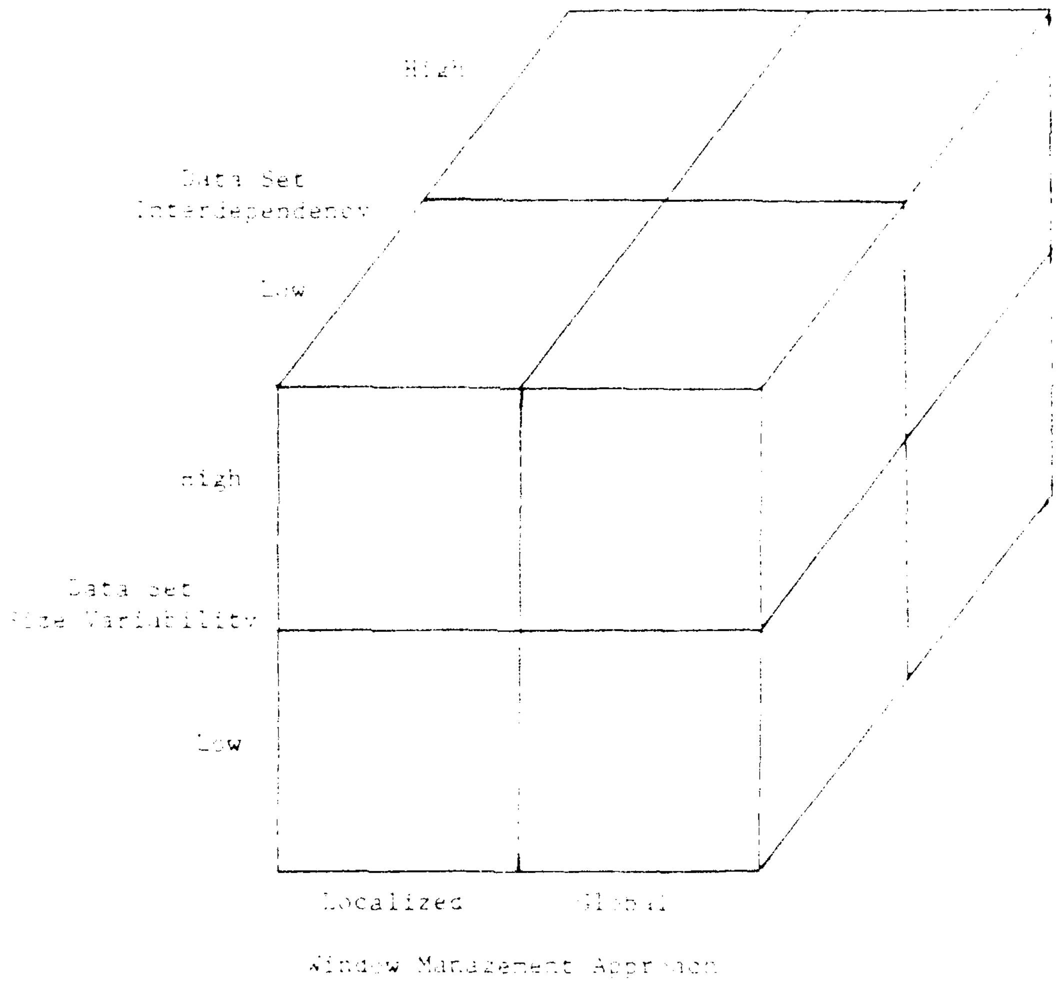


Figure 8   Experimental Design

Procedure

Two window management systems employing the localized and global approaches, respectively, were used in this study. Subjects used these two window management systems to complete the eight task blocks resulting from the crossing of two levels of window management approach, data set size variability, and data set interdependency. The order of administration of these eight task blocks was counterbalanced across subjects. Each of these eight task blocks required the subject to extract information contained in 20 data sets to perform 36 subtasks (i.e., 36 questions requiring the subject to use the window management system to determine specific facts from the 20 data sets). The 36 subtasks in each treatment condition can be divided into two phases.

The first phase included the first 18 subtasks. To complete the first subtask the subject had to open two windows to accommodate two data sets from which the subject needed information. In each of the 3rd, 5th, 7th, 9th, 11th, 13th, 15th, and 17th subtasks, the subject had to open an additional window to accommodate a new data set from which the subject needed information. To complete these and the other subtasks in this phase, the subject might also need to enlarge or reopen windows. Enlarging would be necessary if any of the windows containing data sets necessary to complete a subtask were too narrow to display the full contents of the associated data set. Reopening would be necessary if any of the windows containing data sets necessary to complete a subtask were automatically closed. The first 18 subtasks were categorized as a group because ten windows had to be opened to complete all subtasks in this phase. This was the average number of data sets that could be

[illegible]
display.

The second phase also included [illegible] subtasks. To complete the first subtask in this phase the subject had to open two windows to accommodate two new data sets from which the subject needed information. In each of the [illegible], 5th, 7th, 9th, 11th, [illegible], 13th, and [illegible] subtasks in this phase, the subject had to open an additional window to accommodate a new data set from which the subject needed information. To complete these and the other subtasks in this phase, the subject might need to enlarge a window if a window containing a data set necessary to complete a subtask was too narrow to display the full contents of the data set. The subject might also need to reopen a window if a window containing a data set necessary to complete a subtask was automatically closed.

Each subject was tested over four days. On the first day, the subject signed an informed consent form, read the instructions, and was given tutorials on the use of the window management system and on the nature of the tasks (Appendices A, B, and C). Each subject completed two task blocks per day. Before each of the task blocks, the subject completed a training block to gain familiarity with the commands and features of the window management system he would be using and with the nature of the tasks he would be expected to perform. The subject then performed the actual task block. Next, during a rest break, the subject completed portions of a questionnaire regarding his satisfaction with the window management approach tested in the preceding treatment condition (Appendix [illegible]). At the end of the study, the subject completed a second questionnaire ascertaining his overall satisfaction and preferences for the two window management approaches (Appendix [illegible]).

Dependent Variables

The task completion time, number of window management operations (i.e., openings, enlargings, and reopenings), and number of incorrect solutions were recorded for each of the eight treatment conditions. Task completion time was divided into two primary components: window management time and task solution time.

Window management time included any time the subject spent arranging the display screen into a configuration that was suitable to complete the subtask. Window management time itself was composed of:

1. opening time which included the time spent opening windows;
2. enlarging time which included the time spent enlarging windows;
3. reopening time which included the time spent reopening windows.

Task solution time was the time the subject devoted to determining the specific facts requested, once he had arranged the windows into a configuration suitable to perform this task.

To permit testing of the previously stated research hypotheses, the dependent measures were categorized as follows:

1. Measures based on the performance of subtasks 1 through 18. Subtasks 1 through 18 were performed under conditions in which the number of windows on the display was less than the mean number of data sets that could be fully displayed within the area available on the video display (MxN = 2x5 = 10).

2. Measures based on the performance of subtasks 19 through 36. These subtasks were performed under conditions in which the number of windows on the display was equal to or greater than the mean number of data sets that could be fully displayed within the area available on the video display.

3. Measures based on the overall performance of all 36 subtasks. These measures provide an overall indication of the relative efficiencies of the two window management approaches for the tested task sets.

At the end of each treatment condition portions of a subjective rating scale questionnaire were completed by each participant to permit

[illegible] of the two window management approaches [illegible] perceived ease-of-learning and satisfaction. At the conclusion of the study, the subject completed a second questionnaire ascertaining his overall satisfaction and preference for the two window management approaches.

Analysis

A three-factor, within-subject analysis of variance was performed to determine which window management approach provided the most effective human-computer interface under each of the four decision making scenarios and during each of the two phases tested (less than 10 displayed data sets and 10 or more displayed data sets). Analytical comparisons were performed, where appropriate, to determine the locus of any significant interactions among the independent variables that were identified by the analysis of variance. An analysis of variance summary table is presented in Table I.

Table 1. Analysis of Variance Summary Table for a Three Factor Within Subject Design

Source	df	SS	MS	F
		Between Subjects		
S	(n-1)	SS_S	MS_S	
		Within Subject		
A	(a-1)	SS_A	MS_A	MS_A/MS_{AxS}
AxS	(a-1)(n-1)	SS_{AxS}	MS_{AxS}	
B	(b-1)	SS_B	MS_B	MS_B/MS_{BxS}
BxS	(b-1)(n-1)	SS_{BxS}	MS_{BxS}	
C	(c-1)	SS_C	MS_C	MS_C/MS_{CxS}
CxS	(c-1)(n-1)	SS_{CxS}	MS_{CxS}	
AxB	(a-1)(b-1)	SS_{AxB}	MS_{AxB}	MS_{AxB}/MS_{AxBxS}
AxBxS	(a-1)(b-1)(n-1)	SS_{AxBxS}	MS_{AxBxS}	
AxC	(a-1)(c-1)	SS_{AxC}	MS_{AxC}	MS_{AxC}/MS_{AxCxS}
AxCxS	(a-1)(c-1)(n-1)	SS_{AxCxS}	MS_{AxCxS}	
BxC	(b-1)(c-1)	SS_{BxC}	MS_{BxC}	MS_{BxC}/MS_{BxCxS}
BxCxS	(b-1)(c-1)(n-1)	SS_{BxCxS}	MS_{BxCxS}	
AxBxC	(a-1)(b-1)(c-1)	SS_{AxBxC}	MS_{AxBxC}	$MS_{AxBxC}/MS_{AxBxCxS}$
AxBxCxS	(a-1)(b-1)(c-1)(n-1)	$SS_{AxBxCxS}$	$MS_{AxBxCxS}$	
Total	abcn-1	SS_{Total}		

Factor A Window Management Approach
Factor B Data Set Size Variability
Factor C Data Set Interdependency
a=2, b=2 c=2 n=8

CHAPTER [illegible]

RESULTS

Five dependent measures were employed: window management time, number of window management operations, task solution time, number of incorrect solutions, and total task completion time. Each of these was analyzed separately for the initial portion of the task block when less than 10 data sets had been displayed on the screen, the remainder of the task block when 10 or more data sets had been displayed on the screen, and the entire task block.

Window Management Time and Number of Window Management Operations

Less Than 10 Displayed Data Sets

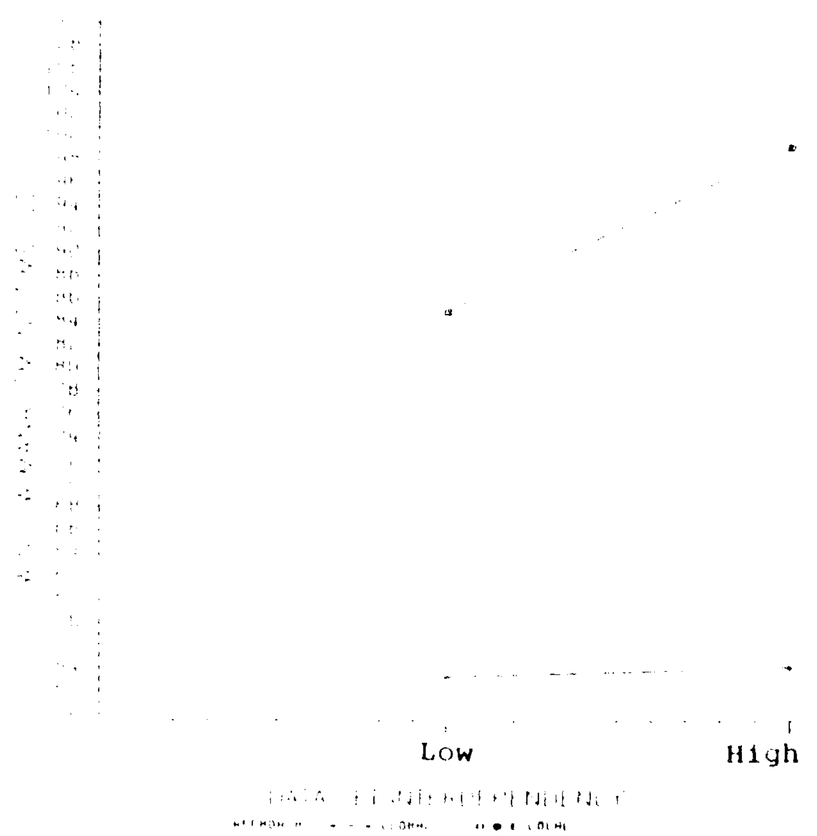
Tables II and III contain the ANOVA summary tables for window management time and number of window management operations, respectively. The Window Management Approach (A) x Data Set Size Variability (Dv) x Data Set Interdependency (Di) interaction is significant for both measures. Figures 9 and 10 depict this interaction for management time and number of management operations, respectively. Simple-effects F-tests (Tables IV and V) indicate that the simple A x Di interaction is significant for both measures when data set size variability is high. Multiple t-tests indicate that when data set size variability is high, the global approach results in significantly less window management time and fewer management operations than the localized approach if data set interdependency is low, while it results in more management time and management operations than the localized approach if data set

Table II. ANOVA Summary Table [illegible] Displayed Data Sets

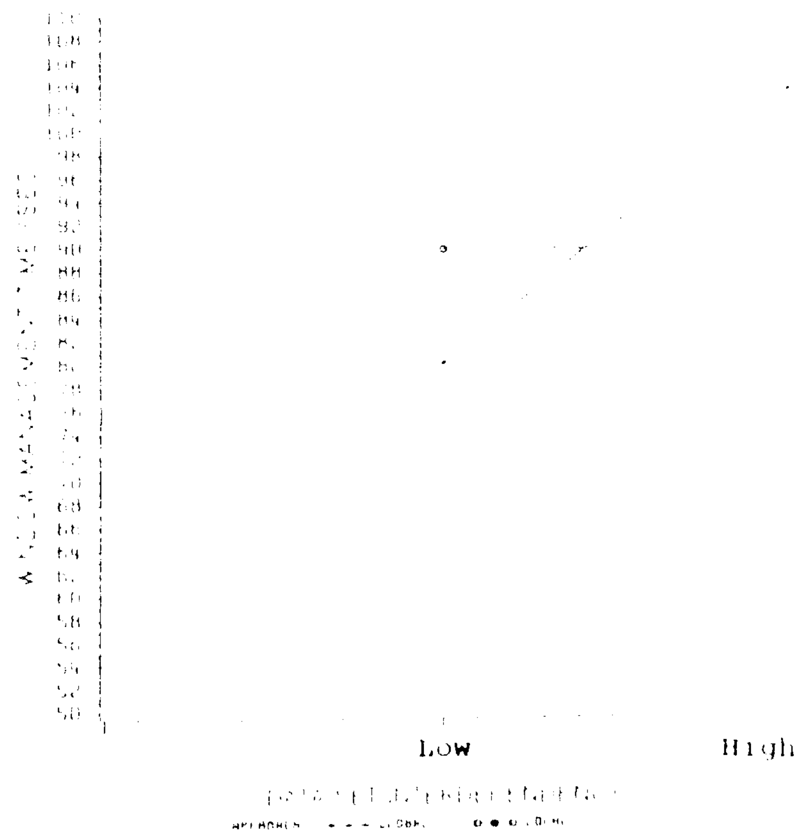
Source	df	SS	F	p
<u>Between</u>				
Subjects (Sub)	7	7628.10		
<u>Within</u>				
Approach (A)	1	5274.21	36.02	0.0005
A x Sub	7	1024.99		
Data Set Size Variability (Dv)	1	5296.75	43.42	0.0003
Dv x Sub	7	853.98		
Data Set Interdependency (Di)	1	1505.15	29.24	0.0010
Di x Sub	7	360.36		
A x Dv	1	6467.18	64.13	0.0001
A x Dv x Sub	7	705.95		
A x Di	1	106.12	0.67	0.4403
A x Di x Sub	7	1110.05		
Dv x Di	1	75.06	0.23	0.6430
Dv x Di x Sub	7	2240.81		
A x Dv x Di	1	1358.94	9.53	0.0176
A x Dv x Di x Sub	7	998.16		
Total	63			

Table [illegible]. ANOVA Summary Table for Number of Window Management Operations (Less Than 7 Displayed Data Sets)

Source	df	SS	F	p
Between				
Subjects (Sub)	7	33.94		
Within				
Approach (A)	1	105.06	70.46	0.0001
A x Sub	7	10.44		
Data Set Size Variability (Dv)	1	126.56	93.87	0.0001
Dv x Sub	7	9.44		
Data Set Interdependency (Di)	1	20.25	10.31	0.0148
Di x Sub	7	13.75		
A x Dv	1	132.25	62.76	0.0001
A x Dv x Sub	7	14.75		
A x Di	1	0.56	0.32	0.5912
A x Di x Sub	7	12.44		
Dv x Di	1	1.56	0.78	0.4051
Dv x Di x Sub	7	13.94		
A x Dv x Di	1	16.00	17.23	0.0043
A x Dv x Di x Sub	7	6.50		
Total	63			

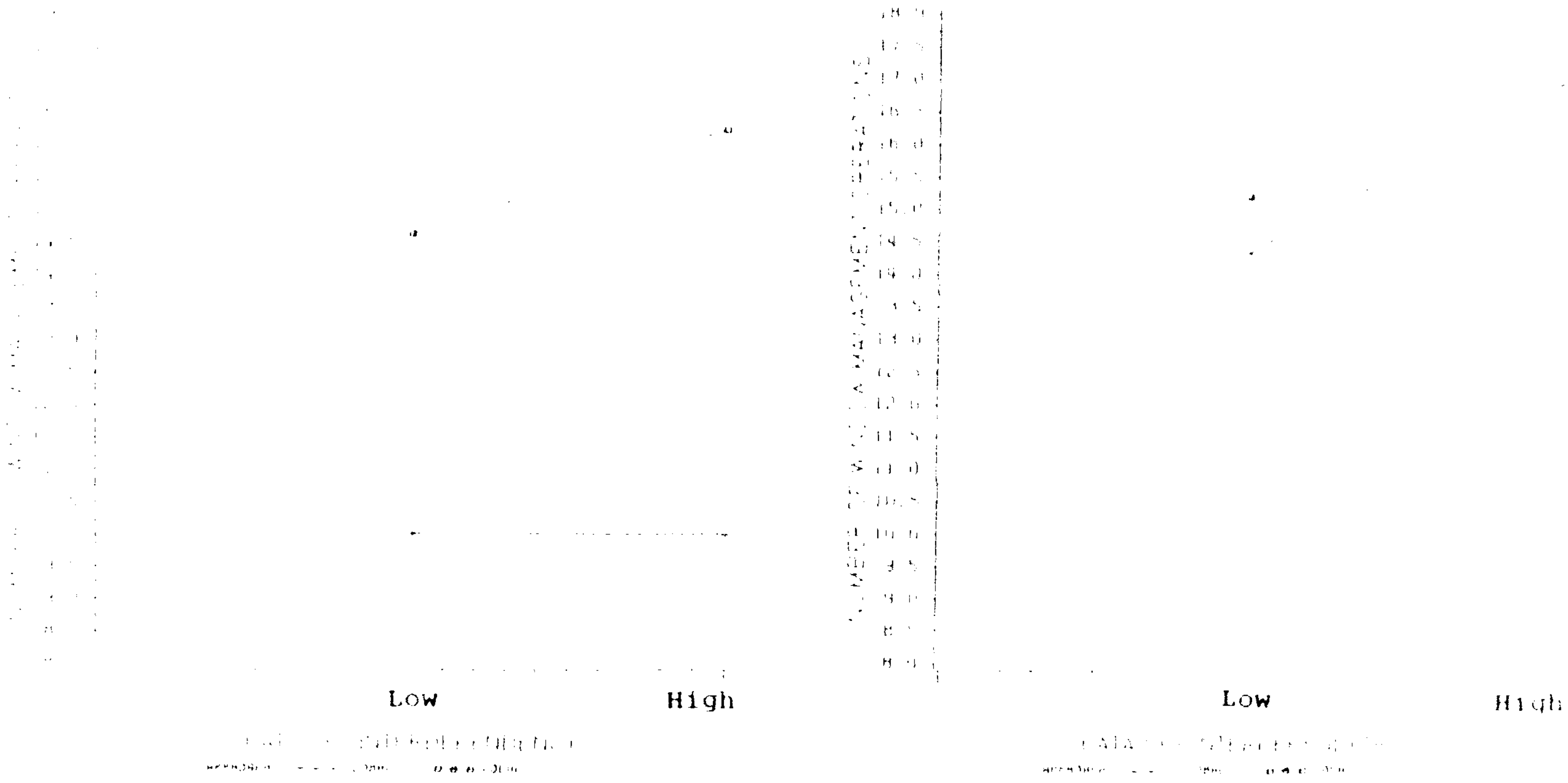


a. Low Data Set Size Variability



b. High Data Set Size Variability

Figure 9. A x Dv x Di Interaction for Window Management Time (Less Than 10 Displaced Data Sets)



a Low Data Set Size Variability

b High Data Set Size Variability

Figure 10 A x Dv x Di Interaction for Number of Window Management Operations (Less Than 10 Displayed Data Sets)

Table [illegible] Summary Table [illegible] Simple Effects [illegible]
Management Time (Less Than [illegible] Displayed Data Set)

Source	df	SS	F	p
Low data set size variability				
Approach (A)	1	11683.47	130.24	0.0001
Data set interdependency (DI)	1	459.42	1.91	0.2091
A x DI	1	348.02	348.02	0.2634
High data set size variability				
Approach (A)	1	[illegible]0.38	0.19	0.6730
Data set interdependency (DI)	1	1126.23	8.62	0.0218
A x DI	1	1112.27	16.46	0.0048

Table [illegible] Summary Table [illegible] Window Management Operations [illegible] Data Sets

Source	df	SS	F	p
Low data set size variability				
Approach (A)	1	236.53	86.15	0.0001
Data set inter-dependency (Di)	1	5.28	2.24	0.1777
A x Di	1	5.28	2.24	0.1777
High data set size variability				
Approach (A)	1	0.78	0.92	0.3703
Data set inter-dependency (Di)	1	16.53	10.31	0.0148
A x Di	1	11.28	31.99	0.0008

interdependency is high (Table VI). This significant simple A x Di interaction suggests that when there are less than ten data sets on the display and data set size variability is high, performance with the global approach is sensitive to changes in data set interdependency, while performance with the localized approach is insensitive.

The simple-effects F-tests on the A x Dv x Di interaction reveal a significant simple main effect of window management approach on both dependent measures when data set size variability is low (see Tables IV and V). This effect indicates that when data set size variability is low, the global approach requires less window management time and fewer window management operations (53.67 s and 10.00 operations) than the localized approach (91.89 s and 15.44 operations) regardless of the level of data set interdependency.

The simple-effects F-tests on the A x Dv x Di interaction also indicate that the simple main effect of data set interdependency is significant for both dependent measures when data set size variability is high. Less window management time and fewer window management operations were needed to complete tasks when the interdependency among data sets was low (85.02 s and 14.81 operations) than when it was high (96.88 s and 16.25 operations). The significant simple A x Di interaction, however, indicates that this effect is valid only for the global approach. Performance of the localized approach is insensitive to changes in data set interdependency when data set size variability is high.

The interaction of window management approach with data set size variability is significant for both measures. Figures 11 and 12 depict this interaction for management time and number of management

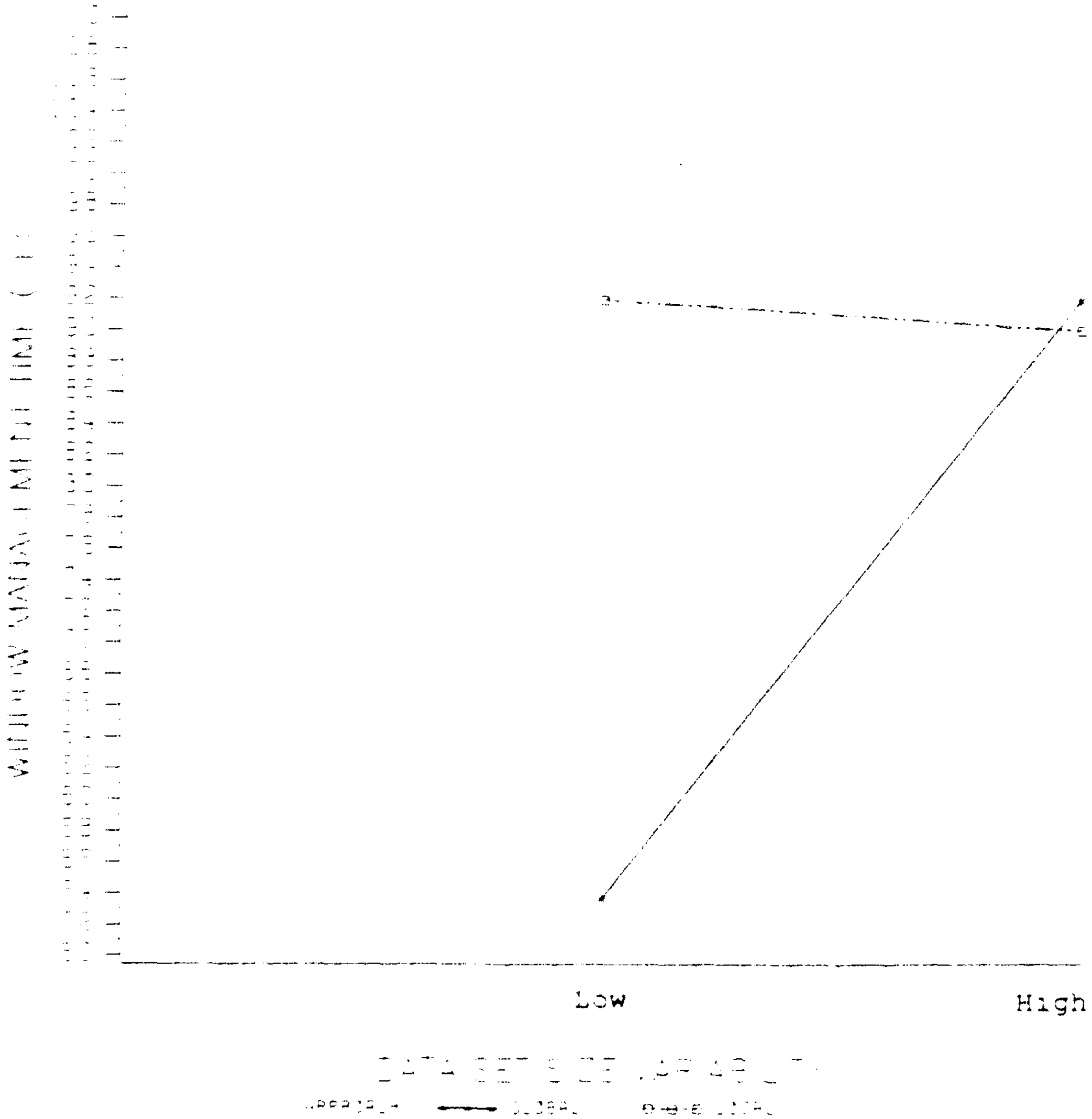
Table [illegible]. Multiple t-tests on the Simple A x B Interaction for High Data Set Size Variability (Less Than 10 Displayed Data Sets)

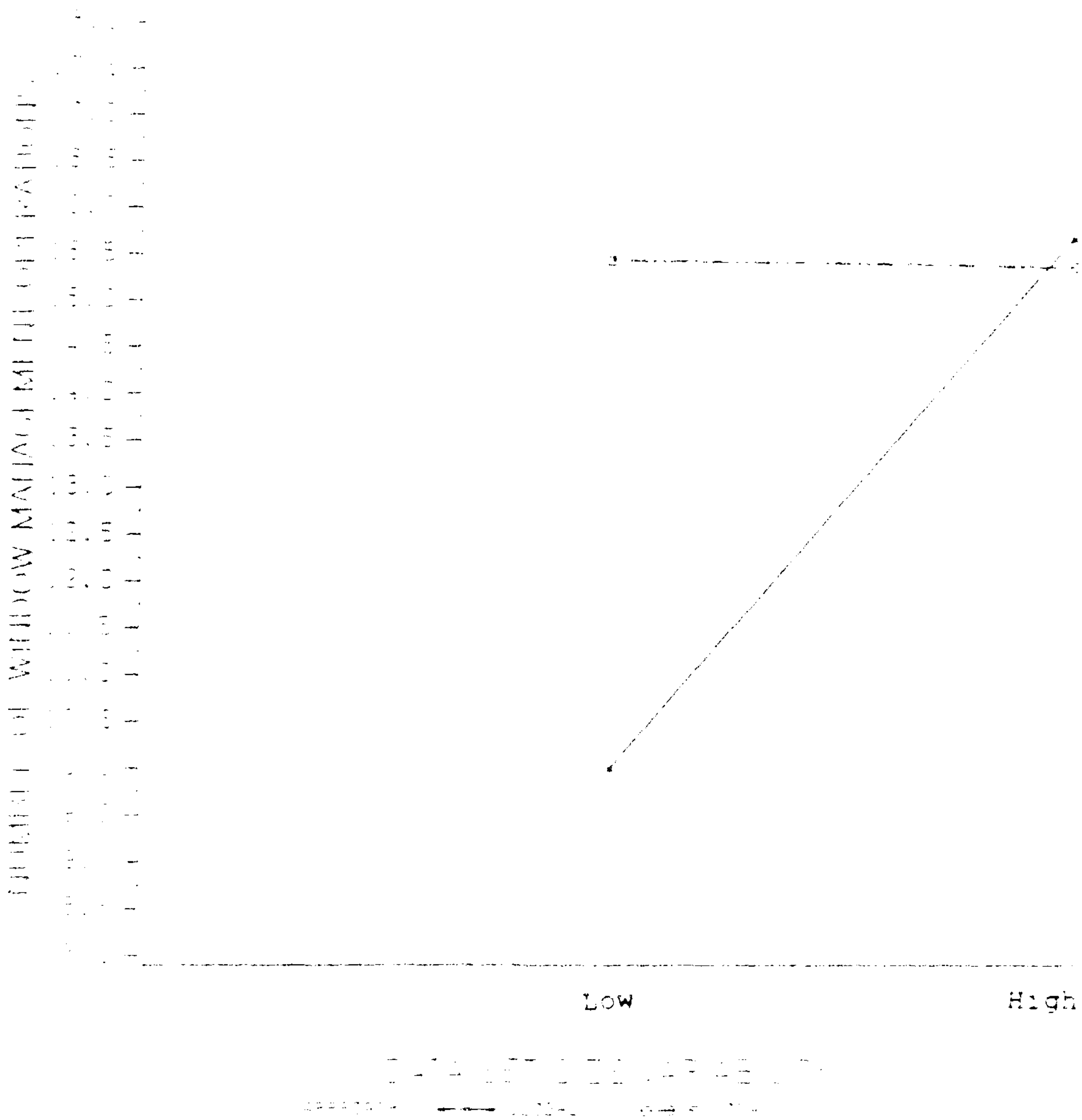
(a) Window Management Time (sec)

Approach		Data Set Interdependency: Low	Data Set Interdependency: High
Approach	Localized	89.94	90.01
	Global	80.10	103.75
		p = 0.0478	p = 0.0124

(b) Number of Window Management Operations

Approach		Data Set Interdependency: Low	Data Set Interdependency: High
Approach	Localized	15.25	15.50
	Global	14.38	[illegible]
		p = 0.0215	p = 0.0015


Low
High



Low
High

operations, respectively. Multiple t-tests show that the global approach results in less window management time and fewer window management operations than the localized approach when data set size variability is low, but is not significantly different from the localized approach when data set size variability is high (Table VII). The underlying A x Dv x Di interaction indicates, however, that the latter result is confounded by data set interdependency. Specifically, the multiple t tests of Table VI indicate that when data set size variability is high, the global approach results in less window management time and fewer window management operations than the localized approach if data set interdependency is low. When both data set size variability and data set interdependency are high, the global approach results in more management time and operations than the localized approach. The significant A x Dv interaction depicted in Figures 11 and 12 suggests that when there are less than 10 data sets on display, performance with the global approach is more sensitive to changes in data set size variability than performance with the localized approach.

The main effects of all three independent variables are significant for both window management time and number of window management operations. Less window manangement time and fewer window management operations were needed to complete tasks for the global approach (72.[illegible]8s and 1[illegible].64 operations) than for the localized approach (90.93 s and 15.[illegible]1 operations). The underlying A x Dv x Di interaction indicates, however, that this effect does not hold generally. The localized approach is superior to the global approach if data set size variability and data set interdependency are high (see Figures [illegible] and [illegible]).

Table VII. Multiple t-tests on the A x DV Interaction for Window Management Times and Number of Window Management Operations (Less Than [illegible] Displayed Data Sets)

a. Window management time (sec.)

Approach		Data Set Size Variability: Low	Data Set Size Variability: High
Approach	Localized	91.89	89.98
	Global	53.63	91.93
		$p = 0.0001$	$p = 0.6002$

b. Number of Window Management Operations

Approach		Data Set Size Variability: Low	Data Set Size Variability: High
Approach	Localized	15.44	10.38
	Global	11.00	15.69
		$p = 0.0001$	$p = 0.5618$

Less window management time and fewer window management operations were needed to complete tasks when the data set size variability was low (72.76 s and 12.72 operations) than when it was high (90.9[illegible] s and [illegible] operations). The underlying A x Dv interaction indicates, however, that this effect does not hold generally. It is due to the superior performance of the global approach when data set size variability is low (see Figures 11 and 12).

Less window management time and fewer window management operations were needed to complete tasks when the interdependency among data sets was low (77.00 s and 13.56 operations) than when it was high (86.70 s and 14.69 operations). The underlying A x Dv x Di interaction suggests that this result is due primarily to improvements in the performance of the global approach at high data set size variability when interdependency is low rather than high.

Ten or More Displayed Data Sets

Tables VIII and IX contain the ANOVA summary tables for window management time and number of window management operations, respectively. The interaction of window management approach with data set interdependency is significant for both measures. Figures 13 and 14 depict this interaction for management time and number of management operations, respectively. Multiple t-tests show that the localized approach results in less window management time and fewer window management operations at both levels of task interdependency (Table X). The significant interaction indicates, however, that the advantage of the localized approach over the global approach is greater when the tasks are highly interdependent. When there are ten or more data sets on the display, performance with the global approach appears to be more

Table VIII. ANOVA Summary Table for Window Management Time [illegible]
Displayed Data Sets

Source	df	SS	F	p
Between				
Subjects (Sub)	7	231923.534		
Within				
Approach (A)	1	206[illegible].54	30.77	0.0009
A x Sub	7	46980.91		
Data Set Size Variability (Dv)	1	41.25	0.03	0.8619
Dv x Sub	7	8859.7[illegible]		
Data Set Interdependency (Di)	1	453400.22	2[illegible]	0.0001
Di x Sub	7	12248.75		
A x Dv	1	1907.29	0.53	0.4919
A x Dv x Sub	7	25397.60		
A x Di	1	30422.34	24.42	0.0017
A x Di x Sub	7	8718.79		
Dv x Di	1	99.65	0.37	0.5376
Dv x Di x Sub	7	15404.85		
A x Dv x Di	1	328.65	0.08	0.7810
A x Dv x Di x Sub	7	28391.49		
Total	63			

Table IX ANOVA Summary Table for Number of Window Management Operations (Ten or More Displayed Data Sets)

Source	df	SS	F	p
<u>Between</u>				
Subjects (Sub)	7	439.75		
<u>Within</u>				
Approach (A)	1	2652.25	111.67	0.0001
A x Sub	7	166.25		
Data Set Size Variability (Dv)	1	25.00	2.29	0.1742
Dv x Sub	7	76.50		
Data Set Interdependency (Di)	1	17226.56	480.54	0.0001
Di x Sub	7	250.94		
A x Dv	1	6.25	0.38	0.5581
A x Dv x Sub	7	115.75		
A x Di	1	370.56	12.33	0.0098
A x Di x Sub	7	210.44		
Dv x Di	1	0.56	0.04	0.8415
Dv x Di x Sub	7	91.44		
A x Dv x Di	1	0.06	0.00	0.9643
A x Dv x Di x Sub	7	203.44		
Total	63			

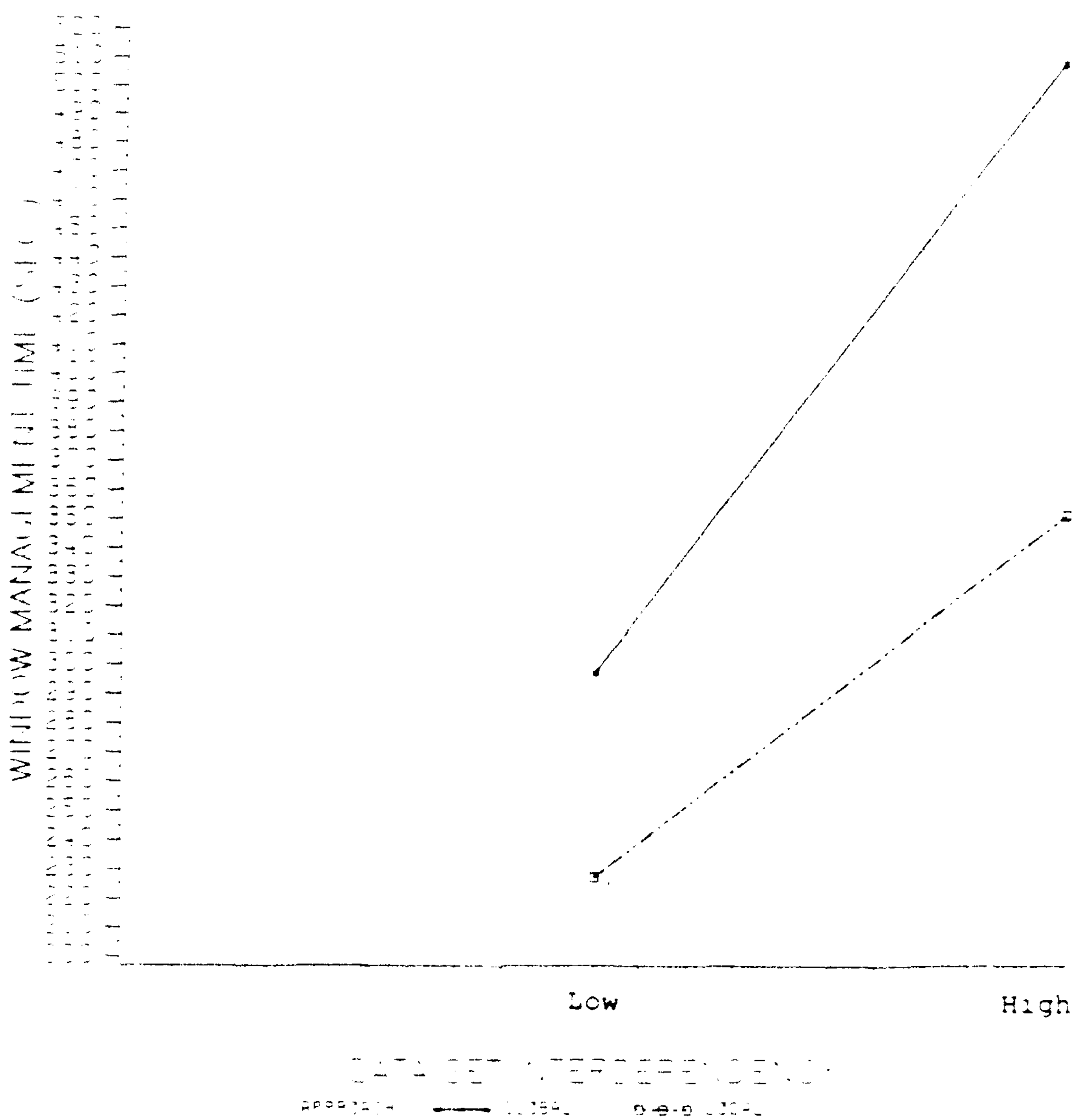


Figure [illegible] A [illegible] Interaction for Window Management Time [illegible] More [illegible] Data [illegible]

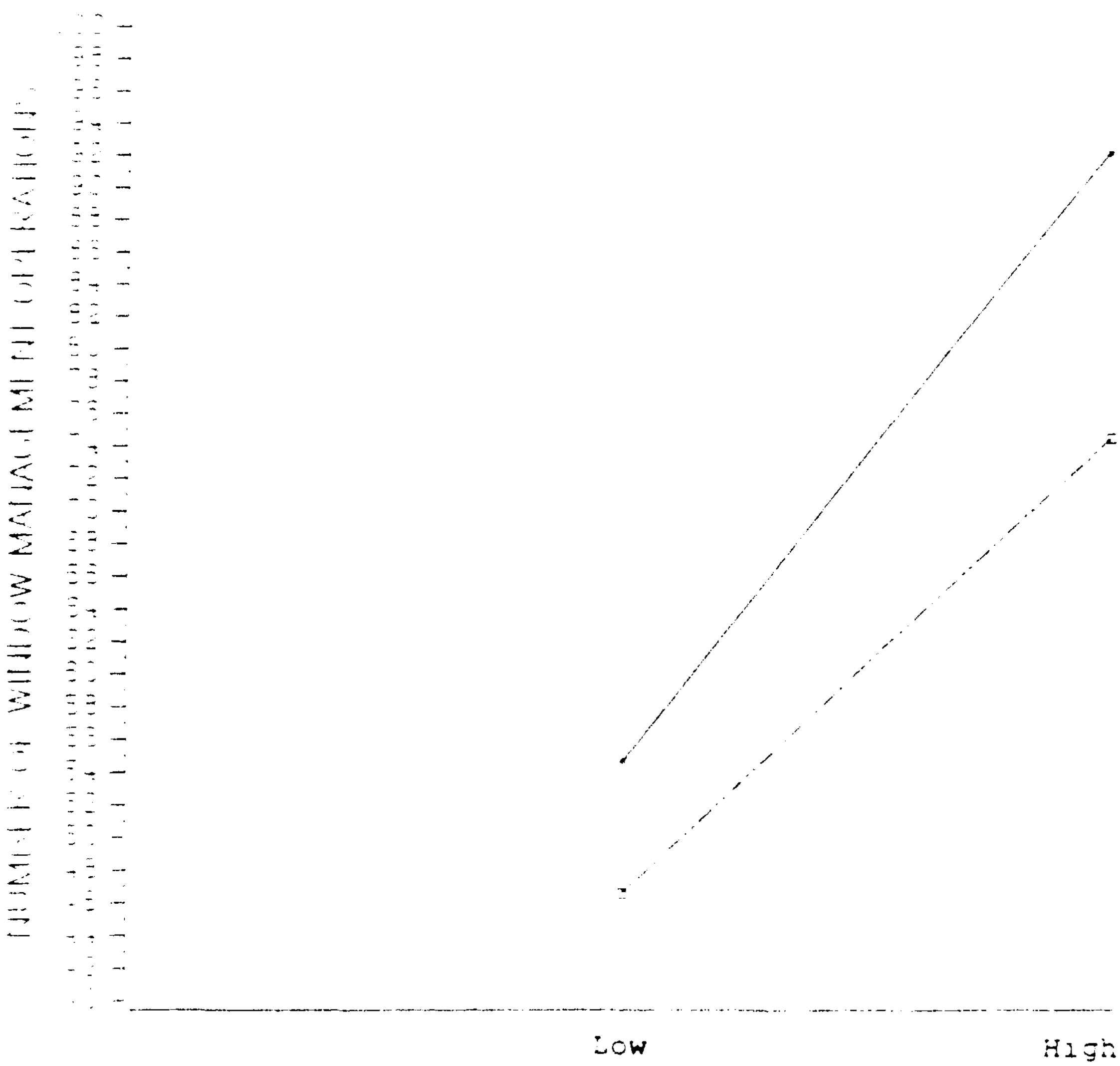

Low
High

Table X. Multiple t tests on the A x II Interaction for Window Management Times and Number of Window Management Operations, Ten or More Displayed Data Sets

a. Window Management Time (sec)

		Data Set Interdependency	
		Low	High
Approach	Localized	227.21	[illegible]
	Global	[illegible]	509.76
		p = 0.0008	p = 0.0001

b. Number of Window Management Operations

		Data Set Interdependency	
		Low	High
Approach	Localized	46.60	74.63
	Global	54.64	92.21
		p = 0.0042	p = 0.0001

sensitive to changes in data set interdependency than performance with the localized approach.

The main effects of window management approach and data set interdependency are also significant for window management time and number of window management operations. Less window management time and fewer window management operations were needed to complete tasks under the localized approach (289.68 s and 60.63 operations) than under the global approach (403.29s and 73.50 operations). Less management time and fewer management operations were needed to complete tasks when the interdependency among data sets was low (262.31 s and 50.66 operations) than when it was high (430.65 s and 83.47 operations).

<u>Entire Task Block</u>

Tables XI and XII contain the ANOVA summary tables for window management time and number of window management operations, respectively. The interaction of window management approach with data set interdependency is significant for both dependent measures. Figures 15 and 16 depict this interaction for management time and number of management operations, respectively. Multiple t-tests show that the localized approach results in less window management time and fewer window management operations than the global approach for both low and high data set interdependency tasks (Table XIII). The interaction indicates that the advantage of the localized approach over the global approach is greater when the tasks are highly interdependent. Figures 15 and 16 also suggest that performance with the global approach is more sensitive to changes in data set interdependency than performance with the localized approach.

Table XI. ANOVA Summary Table for Window Management Time (Entire Task Block)

Source	df	SS	F	p
Between				
Subjects (Sub)	7	303180.48		
Within				
Approach (A)	1	145772.19	17.23	0.0043
A x Sub	7	59223.51		
Data Set Size Variability (Dv)	1	4401.16	3.13	0.1203
Dv x Sub	7	9848.26		
Data Set Inter-dependency (Di)	1	507170.09	373.75	0.0001
Di x Sub	7	9498.78		
A x Dv	1	15402.36	3.93	0.0877
A x Dv x Sub	7	27399.51		
A x Di	1	34117.32	26.03	0.0014
A x Di x Sub	7	9174.05		
Dv x Di	1	347.96	0.10	0.7618
Dv x Di x Sub	7	24525.00		
A x Dv x Di	1	3053.53	0.63	0.4525
A x Dv x Di x Sub	7	33786.36		
Total	63			

Table XII ANOVA Summary Table for Number of Window Management Operations (Entire Task Block)

Source	df	SS	F	p
<u>Between</u>				
Subjects (Sub)	7	658.75		
<u>Within</u>				
Approach (A)	1	1701.56	46.38	0.0001
A x Sub	7	190.94		
Data Set Size Variability (Dv)	1	39.06	3.70	0.0959
Dv x Sub	7	73.94		
Data Set Inter-dependency (Di)	1	18428.06	492.47	0.0001
Di x Sub	7	261.94		
A x Dv	1	196.00	14.22	0.0070
A x Dv x Sub	7	96.50		
A x Di	1	400.00	21.79	0.0023
A x Di x Sub	7	128.50		
Dv x Di	1	4.00	0.18	0.6845
Dv x Di x Sub	7	156.00		
A x Dv x Di	1	18.06	0.66	0.4443
A x Dv x Di x Sub	7	192.44		
Total	63			

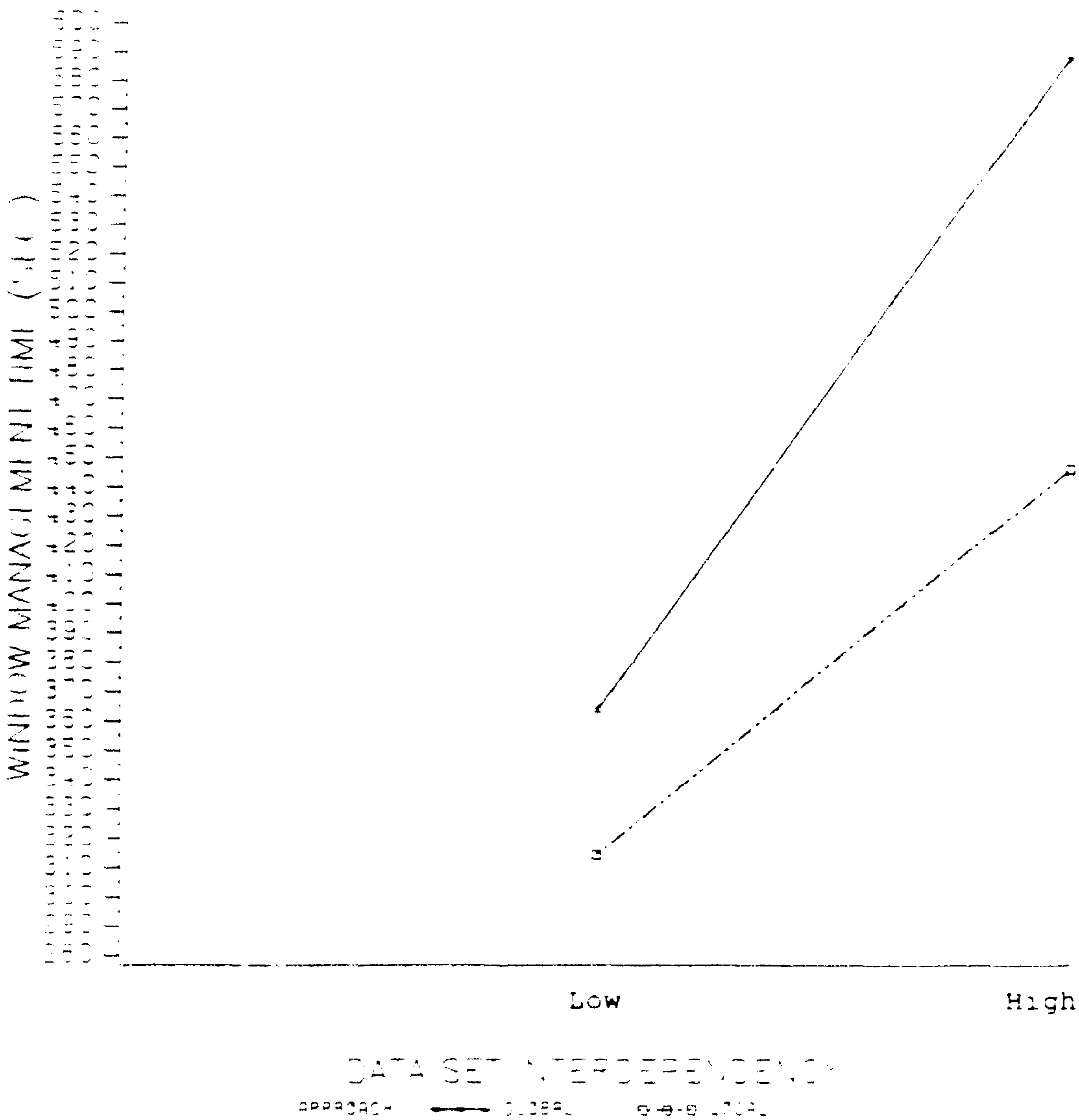


Figure 1[illegible] A x I Interaction for Window Management Time, Entire Task Block

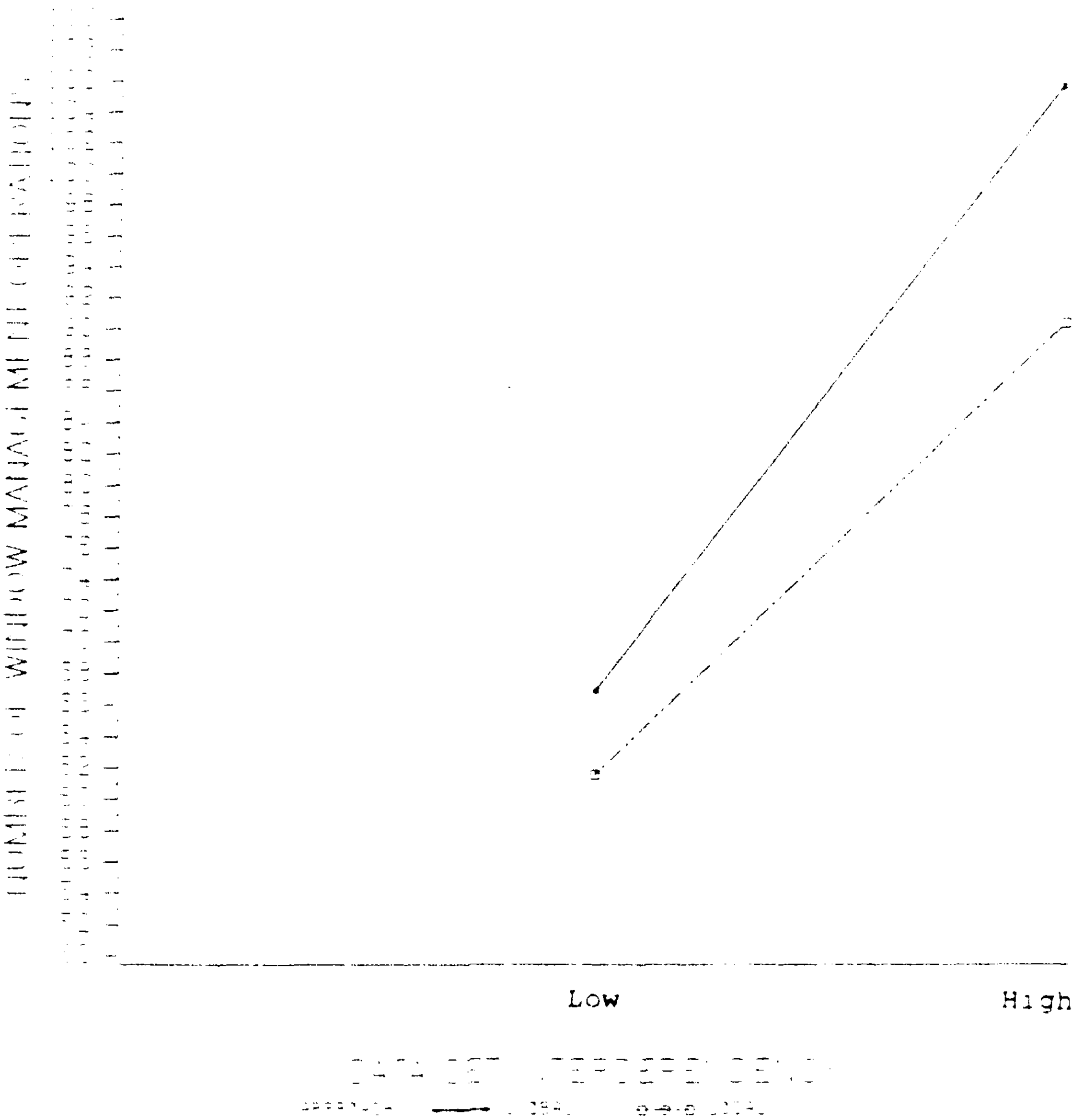


Figure [illegible]. A x D[illegible] Interaction for Number of Window Management Operations Entire Task Block

Table XII [illegible]

[illegible]

		Data Set Interdependence	
		Low	High
[illegible]	Localized	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

		Data Set Interdependence	
		Low	High
[illegible]	Localized	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]

[illegible]

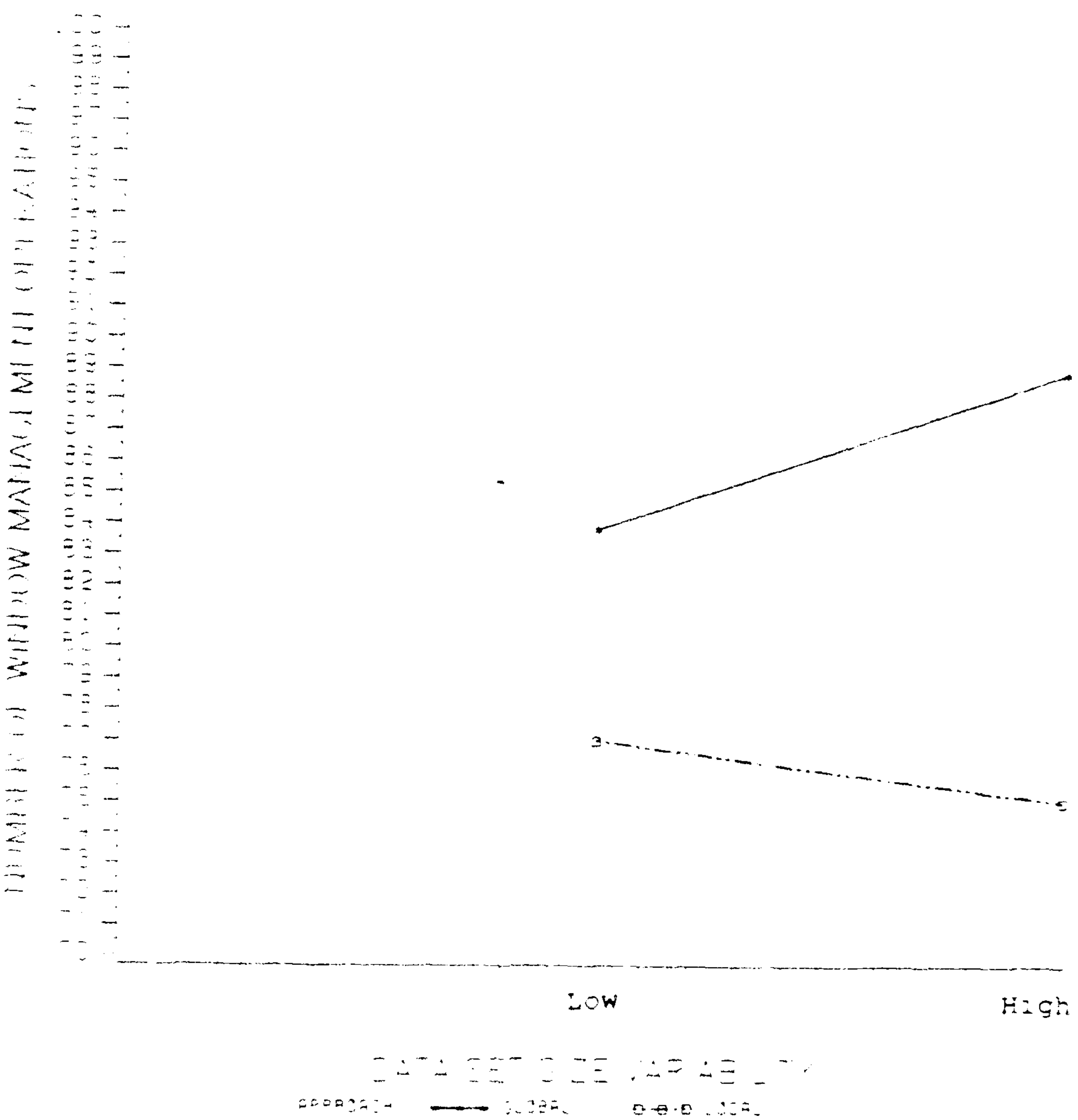
The interaction of window management approach with data set size variability is significant for the number of window management operations only. Figure [illegible] depicts this interaction. Multiple t-tests show that the localized approach results in fewer window management operations than the global approach for both low and high data set size variability tasks (Table XIV). Figure [illegible] suggests that the localized approach is particularly advantageous when the variability of data set sizes is high. It also suggests that performance with the global approach is more sensitive to changes in data set size variability than performance with the localized approach.

The main effects of window management approach and data set interdependency are also significant for window management time and number of window management operations. Less window management time and fewer window management operations were needed to complete tasks under the localized approach (380.61 s and 76.03 operations) than under the global approach ([illegible] s and 86.34 operations). Less management time and fewer management operations were needed to complete tasks when the interdependency among data sets was low (339.32 s and 64.22 operations) than when it was high ([illegible] s and 98.16 operations).

Task Solution Time

Less Than [illegible] Displayed Data Sets

Table XV contains the ANOVA summary table for the task solution time. The task solution time measures the time subjects devoted to determining the specific facts requested. It does not include the time devoted to achieving a window configuration in which these facts may be readily obtained. There are no significant interactions with [illegible] this dependent measure.



[illegible] for Number of Window Management Operations [illegible]

Table XIV. Multiple t-tests on the A x Dv Interaction for Number of Window Management Operations: Entire Task Block.

		Data Set Size Variability	
		Low	High
[illegible]	Localized	[illegible]	[illegible].06
	Global	[illegible].81	88.88
		p = [illegible]	p = [illegible]

Table XV. ANOVA Summary Table for Task Completion Time: Less Than [illegible] Displayed Data Sets

Source	df	SS	F	p
<u>Between</u>				
Subjects (Sub)	7	301463.96		
<u>Within</u>				
Approach (A)	1	1.99	0.00	0.9884
A x Sub	7	60649.14		
Data Set Size Variability (Dv)	1	3846[illegible].14	3[illegible].50	0.0009
Dv x Sub	7	20361.40		
Data Set Inter-dependency (Di)	1	62224.06	12.96	0.0087
Di x Sub	7	33613.02		
A x Dv	1	8180.30	2.35	0.1692
A x Dv x Sub	7	24369.09		
A x Di	1	294.63	0.10	0.7630
A x Di x Sub	7	14566.96		
Dv x Di	1	817.10	0.80	0.4010
Dv x Di x Sub	7	7155.21		
A x Dv x Di	1	174.70	0.02	0.8992
A x Dv x Di x Sub	7	70837.59		
Total	63			

The main effect of data set size variability is significant. Less time was needed to solve tasks when the data set size variability was low ([illegible] s) than when it was high ([illegible] s). The main effect of data set interdependency is also significant. Solution times were shorter when the interdependency among data sets was low (461.30 s) than when it was high (523.66 s). Predictably, window management approach has no effect on the time devoted to determining the requested information once a suitable window configuration has been achieved.

<u>Ten or More Displayed Data Sets</u>

Table XVI presents the ANOVA summary table for task solution time when ten or more data sets had been displayed. There are no significant interaction effects.

The main effect of data set size variability is significant. Less time was needed to solve tasks when the data set size variability was low (533.25s) than when it was high (634.28 s). The main effect of data set interdependency is also significant. Solution times were shorter when the interdependency among data sets was low (494.78 s) than when it was high (672.76 s). Again, window management approach has no effect on the time devoted to determining the requested information.

<u>Entire Task Block</u>

Table XVII contains the ANOVA summary table for the entire block of task solution times. There are no significant interaction effects.

The main effect of data set size variability is significant. Less time was needed to solve tasks when the data set size variability was low ([illegible] s) than when it was high (1163.94 s). The main effect of data set interdependency is also significant. Solution times were

Table XVI. ANOVA Summary Table for Task [illegible] Multi-Displayed Data Sets

Source	df	SS	F	p
Between				
Subjects (Sub)	7	540114.09		
Within				
Approach (A)	1	1833.87	0.09	[illegible]
A x Sub	7	141627.81		
Data Set Size Variability (Dv)	1	163311.96	25.38	0.0015
Dv x Sub	7	45044.39		
Data Set Inter-dependency (Di)	1	506810.51	22.30	0.0022
Di x Sub	7	159103.36		
A x Dv	1	3926.12	0.61	0.4615
A x Dv x Sub	7	45291.82		
A x Di	1	2595.78	0.50	0.5032
A x Di x Sub	7	36482.55		
Dv x Di	1	3834.86	1.08	0.3330
Dv x Di x Sub	7	24825.47		
A x Dv x Di	1	1.03	0.00	0.9949
A x Dv x Di x Sub	7	165145.59		
Total	63			

Table [illegible] ANOVA Summary Table for Task [illegible] Time [illegible] Block

Source	df	SS	F	p
Between				
Subjects (Sub)	[illegible]	[illegible]		
Within				
Approach (A)	1	[illegible]	[illegible]	[illegible]
A x Sub	[illegible]	[illegible]		
Data Set Size Variability (Dv)	1	[illegible]	[illegible]	[illegible]
Dv x Sub	[illegible]	115401.24		
Data Set Inter-dependency (Di)	1	424201.03	20.50	0.0027
Di x Sub	[illegible]	315592.51		
A x Dv	1	23440.76	1.35	0.2836
A x Dv x Sub	[illegible]	121664.80		
A x Di	1	4258.05	0.35	[illegible]
A x Di x Sub	[illegible]	84292.44		
Dv x Di	1	8192.29	1.19	0.3136
Dv x Di x Sub	[illegible]	48651.02		
A x Dv x Di	1	148.87	[illegible]	[illegible]
A x Dv x Di x Sub	[illegible]	442672.39		
Total	63			

shorter when the interdependency among data sets was low [illegible] when it was high [illegible] window management approach has no effect on the time devoted to determining the requested information.

Number of Incorrect Solutions

Tables XVIII, XIX, and XX present the ANOVA summary tables for the number of incorrect task solutions when less than ten data sets had been displayed on the screen, for the remainder of the task block, and for the entire task block, respectively. None of the independent variables, either singly or in combination, affected the number of incorrect task solutions. Table XXI presents the mean numbers of incorrect task solutions entered in each treatment condition for the initial portion of the task block, the remainder of the task block, and the entire task block. The mean numbers of incorrect solutions are generally low, not exceeding two per task block in any of the treatment conditions (out of 36 total solutions per task block). The maximum number of incorrect solutions entered by a subject in a treatment condition was four.

Total Task Completion Time

Less Than 10 Displayed Data Sets

Table XXII contains the ANOVA summary table for the total time required to complete the tasks. This measure is the sum of the window management time and the task solution time. The interaction of window management approach with data set size variability is significant. Figure [illegible] depicts this interaction. Multiple t-tests show that less time was required to complete the tasks with the global approach than with the localized approach when data set size variability was low, but that task completion times were not significantly different for the two

Table XVIII. ANOVA Summary Table for Number of Incorrect Solutions, Less Than 10 Displayed Data Sets

Source	df	SS	F	p
Between				
Subjects (Sub)	[illegible]	[illegible]		
Within				
Approach (A)	1	[illegible]	[illegible]	0.7220
A x Sub	7	[illegible]		
Data Set Size Variability (Dv)	1	0.00	0.00	1.0000
Dv x Sub	7	3.25		
Data Set Inter-dependency (Di)	1	0.25	0.70	0.4304
Di x Sub	7	2.50		
A x Dv	1	0.06	0.08	0.7893
A x Dv x Sub	7	5.63		
A x Di	1	0.06	0.37	0.5630
A x Di x Sub	7	1.19		
Dv x Di	1	0.00	0.00	1.0000
Dv x Di x Sub	7	5.25		
A x Dv x Di	1	0.06	0.26	0.6263
A x Dv x Di x Sub	7	1.69		
Total	63			

Table XIX. ANOVA Summary Table for Number of Incorrect Solutions (Ten or More Displayed Data Sets)

Source	df	SS	F	p
<u>Between</u>				
Subjects (Sub)	7	28.37		
<u>Within</u>				
Approach (A)	1	0.14	0.19	0.6776
A x Sub	7	5.23		
Data Set Size Variability (Dv)	1	0.02	0.04	0.8505
Dv x Sub	7	2.86		
Data Set Inter-dependency (Di)	1	0.39	0.26	0.6253
Di x Sub	7	10.48		
A x Dv	1	0.02	0.05	0.8357
A x Dv x Sub	7	2.36		
A x Di	1	0.02	0.03	0.8786
A x Di x Sub	7	4.36		
Dv x Di	1	0.02	0.02	0.8850
Dv x Di x Sub	7	4.86		
A x Dv x Di	1	0.02	0.05	0.8357
A x Dv x Di x Sub	7	2.36		
Total	63			

Table XX ANOVA Summary Table for Number of Incorrect Solutions (Entire Task Block)

Source	df	SS	F	p
<u>Between</u>				
Subjects (Sub)	7	45.6		
<u>Within</u>				
Approach (A)	1	0.02	0.02	0.9013
A x Sub	7	5.12		
Data Set Size Variability (Dv)	1	0.02	0.02	0.8878
Dv x Sub	7	[illegible].12		
Data Set Inter-dependency (Di)	1	0.02	0.01	0.9298
Di x Sub	7	13.12		
A x Dv	1	0.02	0.02	0.9013
A x Dv x Sub	7	6.61		
A x Di	1	0.14	0.28	0.6115
A x Di x Sub	7	3.48		
Dv x Di	1	0.02	0.01	0.9335
Dv x Di x Sub	7	14.61		
A x Dv x Di	1	0.14	0.02	0.6702
A x Dv x Di x Sub	7	4.98		
Total	63			

Table XXI   Mean Numbers of Incorrect Solutions

(a) Less than 10 displayed data sets

	Approach: Localized		Global	
	Low Inter-dependency	High Inter-dependency	Low Inter-dependency	High Inter-dependency
Low Size Variability	0.75	0.75	0.88	0.63
High Size Variability	0.75	0.63	0.88	0.75

(b) Ten or more displayed data sets

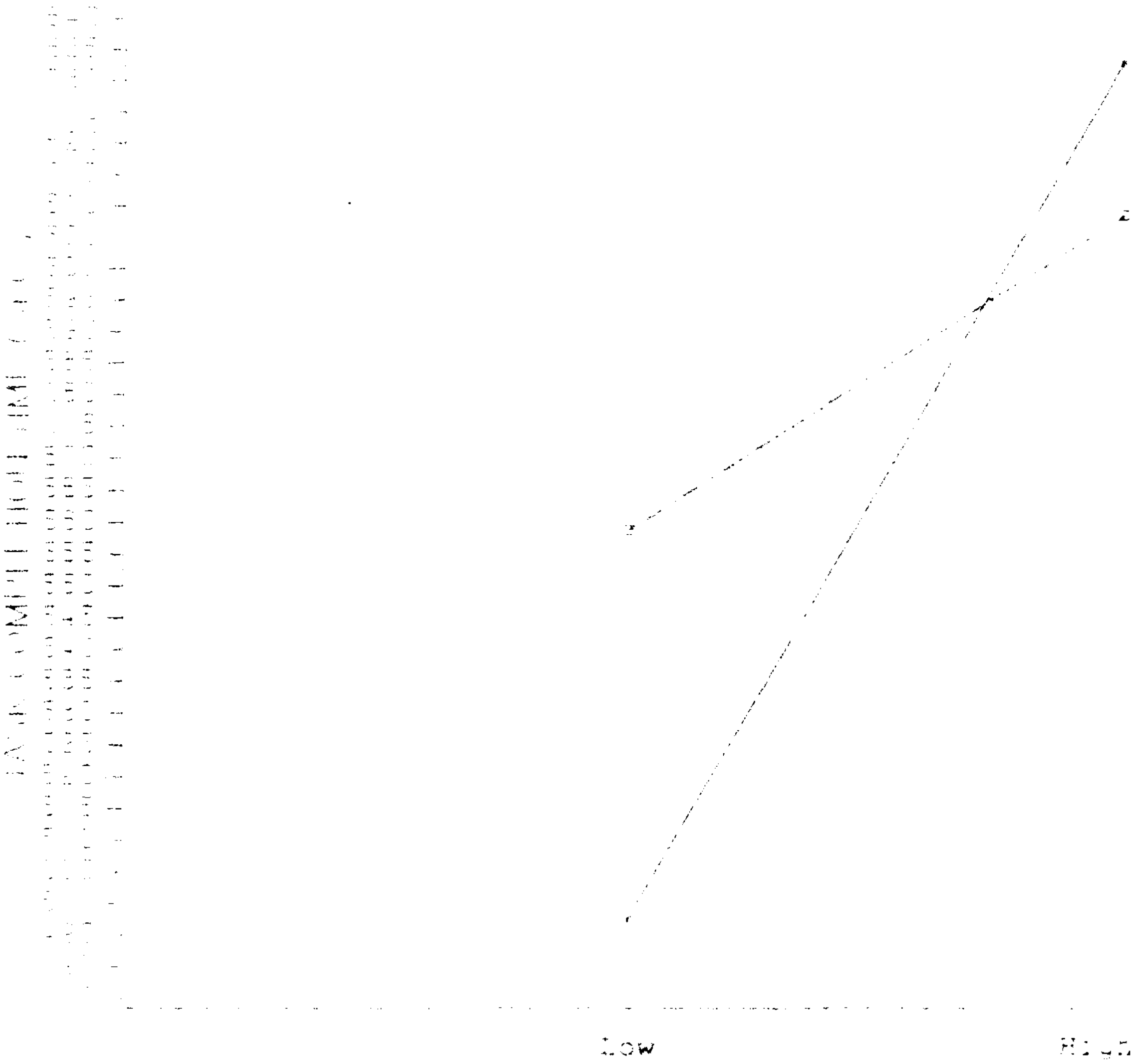
	Approach: Localized		Global	
	Low Inter-dependency	High Inter-dependency	Low Inter-dependency	High Inter-dependency
Low Size Variability	1.13	1.38	1.13	1.25
High Size Variability	1.25	1.38	1.13	1.25

(c) Entire task block

	Approach: Localized		Global	
	Low Inter-dependency	High Inter-dependency	Low Inter-dependency	High Inter-dependency
Low Size Variability	1.88	2.13	2.00	[illegible]
High Size Variability	[illegible]	[illegible]	[illegible]	[illegible]

Table XXII. ANOVA Summary Table for Task Completion Time (Less Than [illegible]
Displayed Data Sets

Source	df	SS	F	p
Between				
Subjects (Sub)	7	340703.57		
Within				
Approach (A)	1	5480.81	0.51	0.4967
A x Sub	7	74681.86		
Data Set Size Variability (Dv)	1	137048.04	47.68	0.0002
Dv x Sub	7	20118.74		
Data Set Inter-dependency (Di)	1	83083.74	17.26	0.0043
Di x Sub	7	33693.51		
A x Dv	1	29194.85	7.03	0.0329
A x Dv x Sub	7	29077.53		
A x Di	1	16.02	0.01	0.9320
A x Di x Sub	7	14318.38		
Dv x Di	1	1387.56	0.72	0.4254
Dv x Di x Sub	7	13562.96		
A x Dv x Di	1	559.09	0.05	0.8303
A x Dv x Di x Sub	7	79056.64		
Total	63			


Low
High

approaches when the data set size variability was high (Table XXIII). The nature of this interaction suggests that when there are less than 10 data sets on the display, performance with the global approach is more sensitive to changes in data set size variability than performance with the localized approach.

Table XXIII. Multiple t Tests on the [illegible] Interaction for Task Completion Time When Less Than 10 Displayed Data Sets

		Approach		
		Localized	Global	
Variability	Low	184.47	[illegible]	$p = 0.0212$
	High	[illegible]	[illegible]	$p =$ [illegible]

The main effects of data set size variability and data set interdependency on the total time required to complete the tasks are also significant. Less time was required to complete the tasks when the data set size variability was low ([illegible] s) than when it was high ([illegible] s). Less time was required to complete the tasks when the interdependency of the data sets was low ([illegible] s) than when it was high ([illegible] s).

Ten or More Displayed Data Sets

Table XXIV contains the ANOVA summary table for the total time required to complete the tasks when ten or more data sets had been displayed on the screen. There are no significant interaction effects. The main effects of data set size variability and data set interdependency are significant. Less time was needed to complete tasks when the data set size variability was low (8[illegible].41 s) than when it was high ([illegible] s). Less time was needed to complete tasks when the interdependency among data sets was low (760.12 s) than when it was high ([illegible].25 s).

The main effect of window management approach is nearly significant ($p = 0.0580$). This result suggests that when there are ten or more data sets on the display, less time is needed to complete tasks under the localized approach (868.10 s) than under the global approach (997.41 s).

Entire Task Block

Table XXV contains the ANOVA summary table for the entire block of [illegible] task completion times. There are no significant interaction effects. The effects of data set size variability and data set interdependency are significant. Less time was needed to complete tasks when the data set size variability was low (1405.78 s) than when it was high ([illegible] s). Less time was needed to complete tasks when the interdependency among data sets was low (1298.93 s) than when it was high ([illegible] s).

Subjective Data

A subjective rating scale questionnaire was completed by each participant at the end of each treatment condition and at the conclusion of

Table XVIII. ANOVA Summary Table for Task Completion Time (Ten or More Displayed Data Sets)

Source	df	SS	F	p
Between				
Subjects (Sub)	7	744252.75		
Within				
Approach (A)	1	247251.39	5.13	0.0580
A X Sub	7	337704.56		
Data Set Size Variability (Dv)	1	178672.12	15.84	0.0053
Dv X Sub	7	78957.19		
Data Set Interdependency (Di)	1	1850291.07	93.88	0.0001
Di X Sub	7	137959.27		
A X Dv	1	17247.90	0.78	0.4063
A X Dv X Sub	7	154707.88		
A X Di	1	9696.59	0.89	0.3760
A X Di X Sub	7	75954.81		
Dv X Di	1	5170.87	0.74	0.4185
Dv X Di X Sub	7	48999.71		
A X Dv X Di	1	377.09	0.01	0.9208
A X Dv X Di X Sub	7	261888.44		
Total	63			

Table XX[illegible] [illegible]A Summary Table for Task [illegible] Block

Source	df	SS	F	p
<u>Between</u>				
Subjects (Sub)	7	1971333.41		
<u>Within</u>				
Approach (A)	1	178051.30	1.78	0.2235
A X Sub	7	698786.44		
Data Set Size Variability (Dv)	1	626203.79	26.09	0.0014
Dv X Sub	7	168161.44		
Data Set Inter-dependency (Di)	1	2713428.44	67.82	0.0001
Di X Sub	7	288582.50		
A X Dv	1	92079.63	2.29	0.1742
A X Dv X Sub	7	281872.32		
A X Di	1	9162.08	0.51	0.4972
A X Di X Sub	7	125145.14		
Dv X Di	1	12190.09	0.87	0.3830
Dv X Di X Sub	7	98499.94		
A X Dv X Di	1	1748.39	0.02	0.8916
A X Dv X Di X Sub	7	612844.03		
Total	63			

the study to permit comparison of the two window management approaches on dimensions of perceived ease of learning and satisfaction (Appendices [illegible] and E). This questionnaire data was analyzed using the Kruskal-Wallis test (Gibbons, 1985). None of the comparisons of the two window management approaches were found to be significant for any of the treatment conditions.

At the conclusion of the study, each participant was also asked to rank the two window management approaches in order of overall preference (Appendix E). Six subjects indicated a preference for the localized approach, while two subjects preferred the global approach. The Friedman test (Gibbons, 1985) was used to analyze this data with window management approach the factor of interest and subjects the blocking factor. The results of this analysis indicate that there is no significant difference in preference between the two window management approaches ($p > 0.1$).

CHAPTER VI

DISCUSSION

The objective of this research was to determine the relative efficiencies of the localized and global approaches to tiled window management under each of several decision making scenarios. The results of the study of human performance using these window management approaches show that their relative efficiencies depend on whether or not the windowed display area is large enough, on average, to permit all open windows to display simultaneously the relevant contents of the data sets associated with them. When there is more than enough display area to permit every open window to display the entire contents of its associated data set, the relative efficiencies of the two window management approaches also depend on the variability in the sizes of the data sets required to perform the tasks and on the level of interdependency among these data sets. The results of the study that lead to these general conclusions are discussed in this chapter.

Less Than 10 Displayed Data Sets

In the study reported in Chapters IV and V, a maximum of two rows of windows were permitted on the display. The sizes of the data sets displayed within the windows were such that, on average, five data sets could be displayed in their entirety within each of these rows. Thus, on average, the total display area was large enough to permit ten open windows to display simultaneously the entire contents of the data sets associated with them.

The first research hypothesis stated in Chapter II predicted that when there were less than 10 windows on the display, the global window management approach would be more efficient than the localized approach if the data set size variability was low. The results of the study support this hypothesis. When less than 10 windows were on the display and data set size variability was low, the global approach required less window management time (Figure 9), fewer window management operations (Figure 11), and shorter total task completion times (Figure 13) than the localized approach. This was true whether data set interdependency was low or high.

The basis for the first hypothesis was that when there is enough display area, on average, to permit all open windows to display simultaneously the entire contents of their associated data sets and the data sets are approximately equal in size, it is likely that each of the windows contains space in excess of that required to display the associated data set. Thus, if an existing window needs to be enlarged or a new window needs to be opened, the small amount of space that will be taken from each window to accomplish this operation under the global approach will often leave these windows sufficiently large to continue display of the full associated data sets. Under the localized approach, however, space will be taken from only one or two windows. The large amount of space that each of these windows must give up may leave these windows too small to continue display of the full associated data set. Thus, enlarging an existing window or opening a new window may have to be followed by additional window enlarging operations when the localized window management approach is used.

[illegible] a maximum of M = 2 rows of windows was permitted on the display and an average of N = 5 data sets could be completely displayed within each of these rows. Given the basis of the research hypothesis just stated, however, the advantage of the global approach over the localized approach would be expected to hold, and even increase, when N, the average number of data sets that can be completely displayed in each row, is greater than five and there are less than MxN windows on the display.

The second research hypothesis stated in Chapter III predicted that when there were less than 10 windows on the display, the localized window management approach would be more efficient than the global approach if both the data set size variability and the data set interdependency were high. The results of the study support this hypothesis. When less than 10 windows were on the display and both data set size variability and data set interdependency were high, the localized approach required less window management time (Figure 9) and fewer window management iterations (Figure 10) than the global approach.

The basis for the second hypothesis was that when there is enough display area, on average, to permit all open windows to display simultaneously the entire contents of their associated data sets and the data sets vary greatly in size, it is likely that some windows contain a great deal more space than that required to display their associated data sets, while other windows do not contain much excess space. If the data sets required to perform a task are highly interdependent, the full contents of several of these data sets may need to be displayed simultaneously to permit performance of a task. If an existing window needs to be enlarged or a new window needs to be opened, the localized

approach permits the user to take space from only one or two windows to meet the needs of the operation and it may be possible to take space only from those windows with sufficient excess space to meet the needs of the operation. Additional enlarging operations may be necessary only if the data sets associated with the affected windows are needed to complete later tasks. Under the global approach, more windows would be affected by the operations, increasing the likelihood that windows without much excess space would be reduced below the size needed to view their associated data sets. This, in turn, would increase the likelihood that additional enlarging operations would be required to complete the current or later tasks when the global management approach is used.

While the study tested a situation in which an average of N = 5 data sets could be completely displayed within each row of windows, the global approach would affect even larger numbers of windows when an existing window needs to be enlarged or a new window needs to be opened and the value of N is greater than five. Thus, the advantage of the localized approach would be expected to hold, and even increase, when N is greater than five and there are less than MxN windows on the display.

No hypotheses were stated for the case in which there are less than MxN windows on the display, data set size variability is high, and data set interdependency is low. The results of the study indicate, however, that when there were less than 10 windows on the display, the global window management approach required less window management time (Figure 9) and fewer window management operations (Figure 10) than the localized approach when data set size variability was high and data set interdependency was low. The difference in performance between the two window management approaches, while significant, was smaller than the

differences observed in the cases for which the research hypotheses provided predictions of the results. Because the basis of the global approach's advantage over the localized approach in this case is not clear and the observed differences are relatively small, there is little support for a conjecture that the advantage of the global approach might hold for values of N other than the tested value of five.

Ten or More Displayed Data Sets

When more than ten windows were displayed simultaneously, the total display area was, on average, not large enough to permit viewing of the entire contents of the associated data sets. The third research hypothesis stated in Chapter III predicted that when there were ten or more windows on the display, the localized window management approach would be more efficient than the global approach if the interdependency among data sets was high. The results of the study support this hypothesis and suggest that the localized approach is more efficient than the global approach even when the interdependency among data sets is low. When ten or more windows were on the display, the localized approach required less window management time (Figure 13) and fewer window management operations (Figure 14) than the global approach. The advantage of the localized approach over the global approach was significant for both levels of data set interdependency, but was greater when the interdependency among data sets was high. The advantage of the localized approach was not affected by the level of data set size variability.

The basis for the third hypothesis was that when there is not enough display area, on average, to permit all open windows to display simultaneously the entire contents of their associated data sets, it is likely that the subtraction of any space at all from a window will

reduce its size below that required to display the full contents of its associated data set. If an existing window needs to be enlarged or a new window needs to be opened, the localized approach may reduce only one or two windows below the size required to view their full contents. Additional enlarging operations will be necessary only if the data sets contained in these windows are necessary to complete the current task or subsequent tasks. Under the global approach, however, several windows will be reduced below the size needed to view their full contents, increasing the likelihood that additional enlarging operations will be required to complete the current or subsequent tasks. The likelihood that additional enlarging operations will be required under the global approach is particularly high when the data sets required to complete tasks are highly interdependent, because in this case the full contents of several data sets may have to be displayed simultaneously to permit performance of the task.

The study tested a situation in which an average of $N = 5$ data sets could be completely displayed within each row of windows. The global approach would affect even larger numbers of windows when an existing window needs to be enlarged or a new window needs to be opened and the value of N is greater than five. Thus, the advantage of the localized approach is expected to hold, and even increase, when N is greater than five and there are MxN or more windows on the display.

CHAPTER VII

CONCLUSION

Recommendations

The objective of this research was to determine the relative efficiencies of the localized and global approaches to tiled window management under each of several decision making scenarios. Each of these decision making scenarios is characterized by its location along each of three dimensions

1. Whether or not the windowed display area is large enough, on average, to permit all open windows to display simultaneously the relevant contents of the data sets associated with them.

2. The variability in the sizes of the data sets required to perform the decision making tasks.

3. The level of interdependency among the data sets required to perform the decision making tasks

The results of the study of human performance using the localized and global window management approaches led to the following empirically supported guidelines for the design of window management systems

When there is enough display area, on average, to permit all open windows to display simultaneously the relevant contents of the data sets associated with these windows the following alternatives are recommended.

If the variability in the sizes of the data sets required to perform the decision making tasks is low, the global window management approach is recommended. This recommendation holds both when the interdependency among the data sets required to perform the tasks is low and when it is high

If both the size variability and the interdependency among the data sets required to perform the decision making tasks are high, the localized window management approach is recommended.

This research does not provide sufficient support for a general recommendation applicable to the case in which the data set size variability is high and the interdependency among data sets is low. For the particular decision making environment tested, however, the global window management approach proved to be superior to the localized approach in this case.

When there is not enough display area, on average, to permit all open windows to display simultaneously the relevant contents of the data sets associated with these windows, the localized window management approach is recommended. This recommendation holds regardless of the levels of size variability and interdependency among the data sets required to perform the decision making tasks.

Limitations and Suggestions for Future Research

The research hypotheses stated in Chapter III were supported empirically by the results of the study reported in Chapters IV and V. The hypotheses are stated for a situation in which a maximum of M rows of windows is permitted on a display and an average of N data sets can be completely displayed within each of these rows. The study reported in Chapters IV and V tested a situation in which M was set equal to 2 and N was set equal to 5. Thus, empirical support for the research hypotheses is provided by the study only for these specific values of M and N. The bases for the research hypotheses suggest, however, that they should hold for values of M other than two and for values of N

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NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA

LOCALIZED AND GLOBAL APPROACHES FOR TILED WINDOW MANAGEMENT BY: JF CHEN, JS GREENSTEIN

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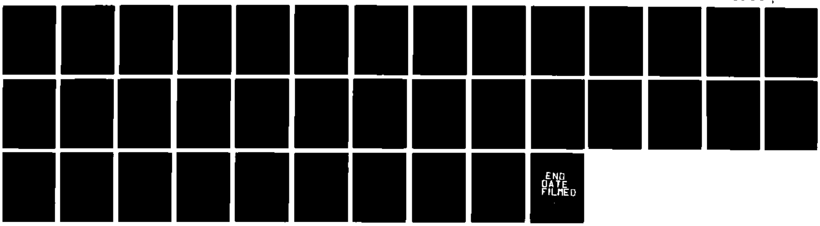


[illegible]

[illegible] research [illegible] window management [illegible] vertical lengths of both the windows [illegible]. The [illegible] were fixed and equal to one half the display height. [illegible] window management system may permit the vertical lengths of [illegible] rows of windows to be adjusted. It may also permit the vertical lengths of windows within a row to be adjusted independently of each other. It is possible that the hypotheses stated in this research could be generalized to the more general situation in which tiled window dimensions may be adjusted in two dimensions rather than in one. It is suggested that future research pursue this possibility.

This research explicitly considered a situation in which the performance of a decision making task required access to the entire contents of a data set. That is, the task required the decision maker to view all the graphic objects in a data set if he was to be certain that he had located all the objects relevant to a particular task. In many realistic decision making situations, only portions of data sets may need to be accessed to perform decision making tasks. In such situations it would probably be appropriate to include a scrolling capability within the window management system to permit the user to locate the relevant portion of a data set within a window that [illegible] contain the full data set [illegible] the relevant portion of the data set [illegible].

[illegible] number of [illegible] row of windows, it would be more appropriate [illegible] the average number of [illegible] task completion within a row. It is suggested that future research be conducted to determine whether the hypotheses stated in this research might then apply to this more general situation.

This research assumed a situation in which windows were closed only when the enlarging or opening of one window reduced the amount of space available to another window in the same row below a specified minimum acceptable width. Also, when a window was opened, the amount of space allocated to the new window was set equal to 1/N of the total row width, where N represents the number of windows present in the row upon introduction of the new window. These design decisions permitted the user to manage windows using a very small set of commands. The user would certainly gain additional flexibility if additional window management functions were introduced, such as a "close window" function, a "replace window" function, and an "open window" function which also permitted the user to specify the width of the new window. This flexibility might increase efficiency by permitting the user to exert greater control over the manner in which space is made available for enlarged and newly opened windows. It is suggested that future research be conducted to determine whether the additional control offered by this additional functionality outweighs the complexity added to the window management task.

The literature review presented in Chapter II identified seven categories of human factors issues directly relevant to the design of window based human computer interfaces [illegible]

example, [illegible] window management systems [illegible] different functions. This research considered [illegible] of these func[illegible] [illegible] et al. (1984) also stated that current window [illegible] can be grouped within several different categories and subcategories. This research considered the subcategory of tiled window management systems.

Very little empirical research of human performance with window management systems has thus far been conducted. Clearly, much research remains to be done before system designers can be provided with a comprehensive set of guidelines for the design and use of window management systems that enhance [illegible] performance and satisfaction.

APPENDICES

[illegible]

[illegible]

The purpose of this document [illegible] this experiment and to inform [illegible] rights as a participant [illegible]

This study investigates two different approaches commonly used in tiled window systems. The first, termed the <u>localized approach</u>, creates space for a new or enlarged window by taking space from adjacent windows. When the adjacent windows do not have enough space to meet the needs of the new or enlarged window, space is also taken from the next most adjacent window. The second, termed the <u>global approach</u>, creates space for a new or enlarged window by taking equal amounts of space from all the other windows in the same row. The information this study will provide is needed if window management systems are to be employed effectively. This research is being conducted in the Human-Computer Systems Laboratory of the Department of Industrial Engineering. Dr. Joel S. Greenstein is administering this study under a contract with the Naval Ocean Systems Center.

Your task as a participant in this study is to determine specific facts from a number of data sets using the window management system. Participation in the study is entirely voluntary. If you choose to participate, you will receive instruction in the use of the software, you will participate in four experimental sessions, and you will be asked to complete a questionnaire regarding the window management approaches used in the test. The experimental sessions will consist of two 50-minute blocks of trials with brief rest breaks between blocks. The entire experiment will require about seven hours to complete. You will receive a voucher in the amount of 30 dollars upon completion of the study, including training, rest breaks, and questionnaire administration.

We hope that this experiment will be an interesting experience for you. It is possible that at times you may feel frustrated or stressed. Your performance on the task reflects the difficulty of the task, not your personal abilities or talents.

Please note:

1. You have the right to stop participating in the experiment at any time. If you choose to terminate your participation in the experiment, you will receive payment only for the proportion of time you participated.

2. You have the right to see your data and to withdraw them from the experiment. If you decide to withdraw your data, please notify the experimenter immediately. Otherwise, identification of your particular data will not be possible, because the data will be separated from your code number.

[illegible] have the right to [illegible] of the [illegible] experiment. If after participation you wish to receive information regarding this study please include your address [illegible] months below with your signature below. If more detailed information is desired than [illegible] summary [illegible] contact the I.E. Department and a full report will be made available to you.

Your participation is greatly appreciated. If you have any questions about the experiment or your rights as a participant, please do not hesitate to ask. We will answer your questions as openly and honestly as is possible without biasing the experimental results. Should you have any additional questions or problems contact Dr. [illegible] Greenstein, Associate Professor, at [illegible]

Your signature below indicates you have read the above stated rights and you consent to participate. If you include your printed name and address below, a summary of the experimental results will be sent to you.

Signature

Printed Name

Address

City, State, Zip

[illegible]

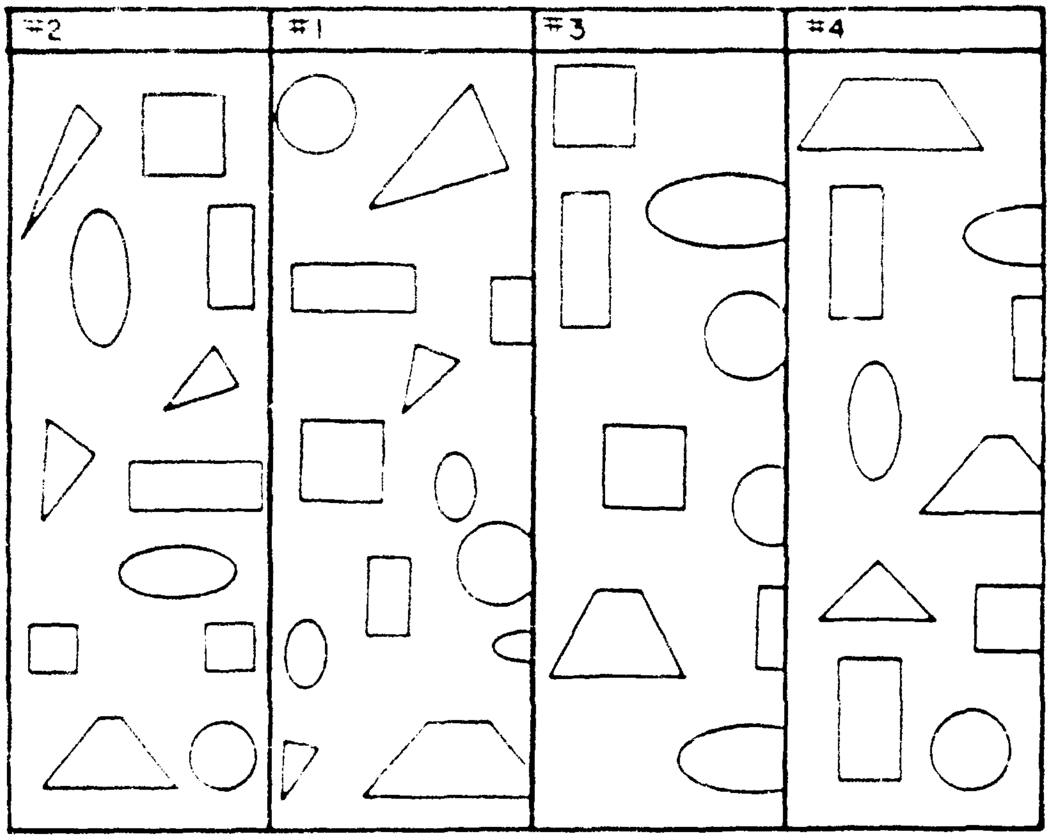
[illegible]

Welcome to The Department of [illegible] [illegible] [illegible] [illegible] systems laboratory. We appreciate your participation in this [illegible]

A windowing system allows the user of a computer to simultaneously access and act upon multiple sources of information as if he had multiple video displays connected to one computer. Figure B-1 shows four windows displayed on the video display at once. Each of these windows contains different information. This study investigates two different approaches commonly used in "tiled" window management systems. The first, termed the localized approach, creates space for a new or enlarged window by taking space from adjacent windows. When the adjacent windows do not have enough space to meet the needs of the new or enlarged window, space is also taken from the next most adjacent wind[illegible]. The second, termed the global approach, creates space for a new or enlarged window by taking equal amounts of space from other windows in the same row of the display. Figures B-2, B-3, and B-4 show the difference between these two approaches.

[illegible]

The hardware configuration will consist of a Tand[illegible] personal computer with keyboard interfaced to a Tandy VM-[illegible] text monitor and an NEC graphics monitor. All textual input and output (questions that you are to answer, window management commands that you enter, answers that you enter, and feedback directed to you regarding your answers) [illegible] [illegible] to the text monitor. All data sets [illegible] [illegible] [illegible] [illegible] displayed in a graphical windowed environment [illegible] the [illegible] [illegible] [illegible] software has been written to enable [illegible] [illegible] [illegible]



#2
#1
#3
#4

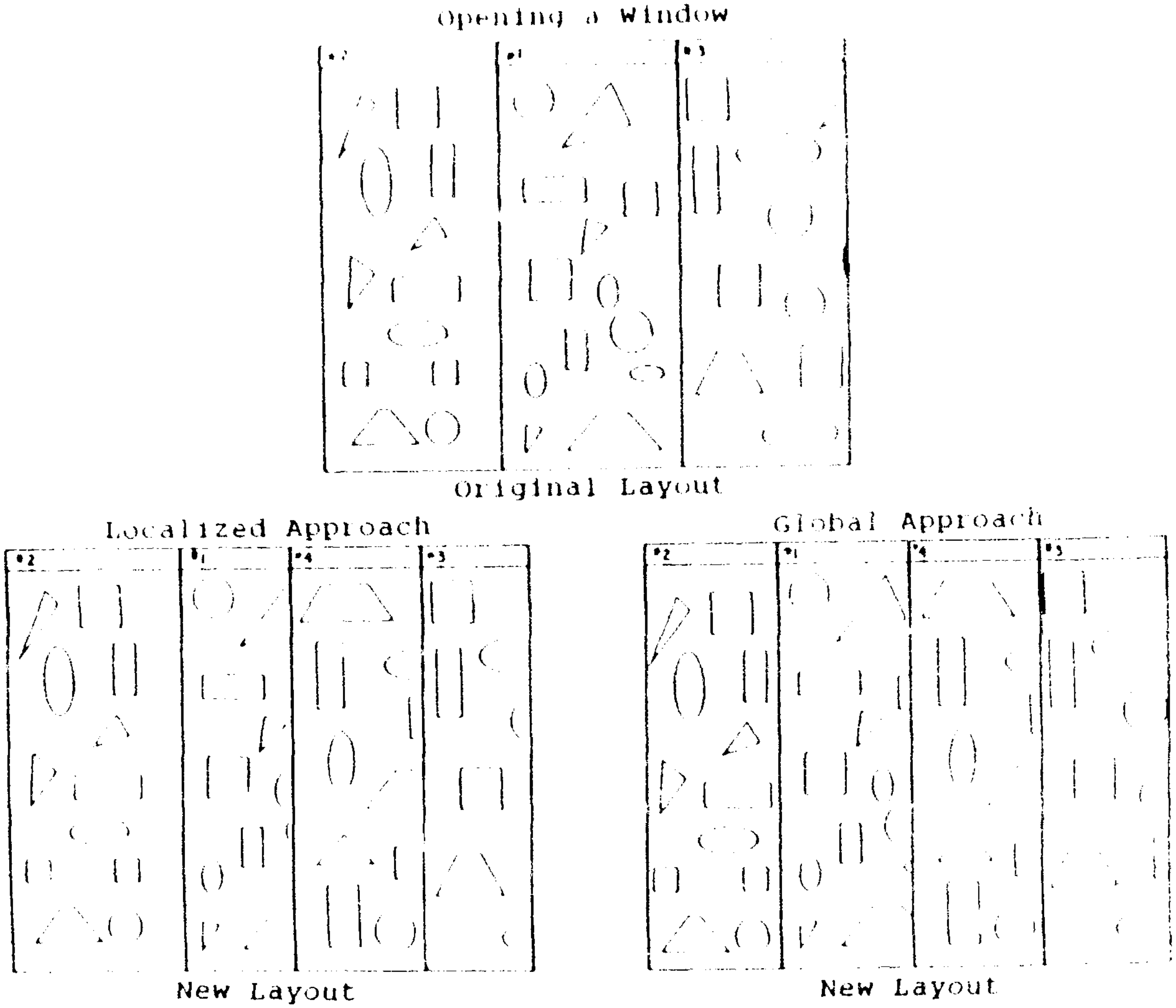


Figure [illegible] Localized Approach vs. Global Approach in Opening a Window (a)

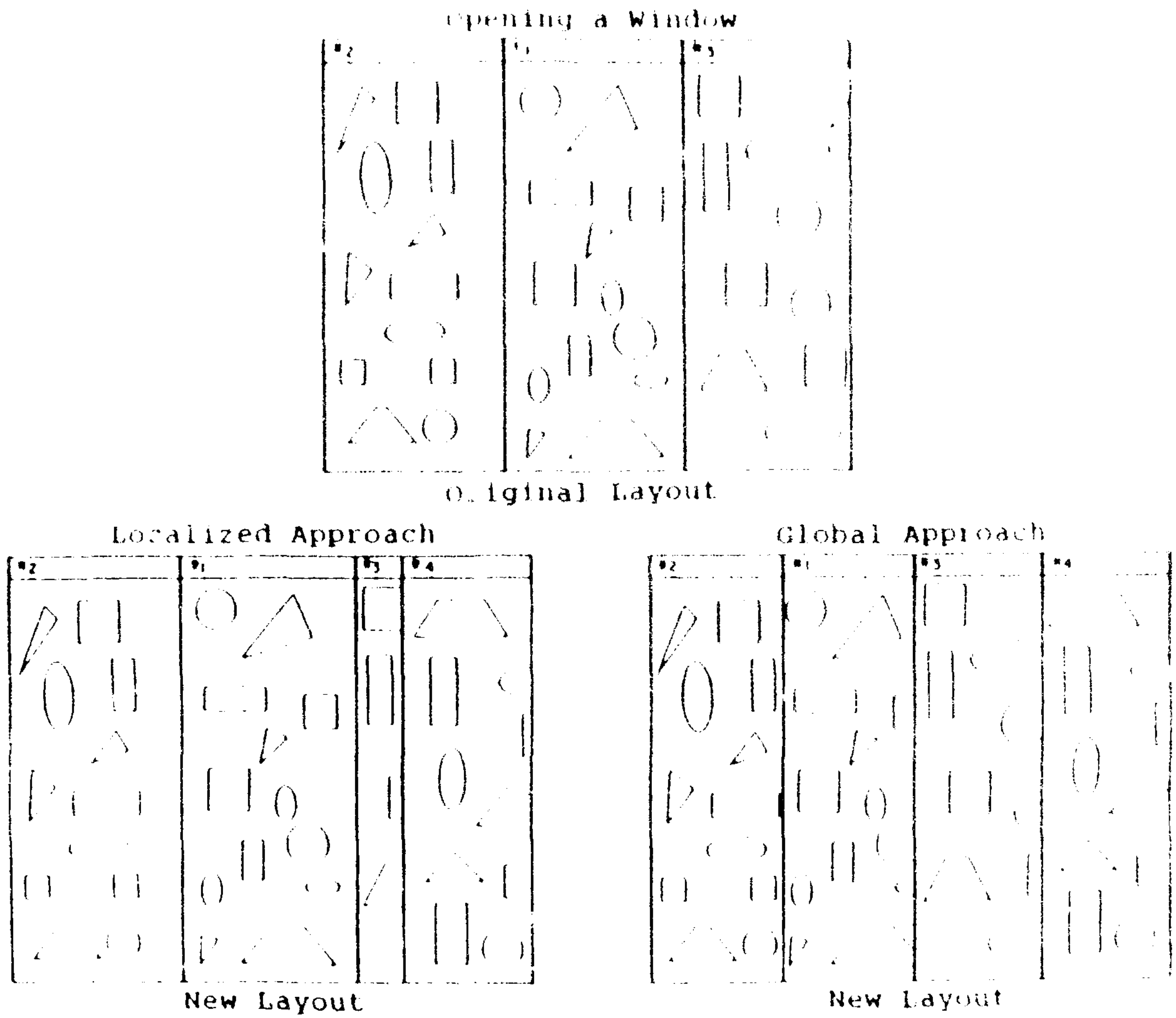


Figure B.3 Localized Approach vs. Global Approach in Opening a Window (b)

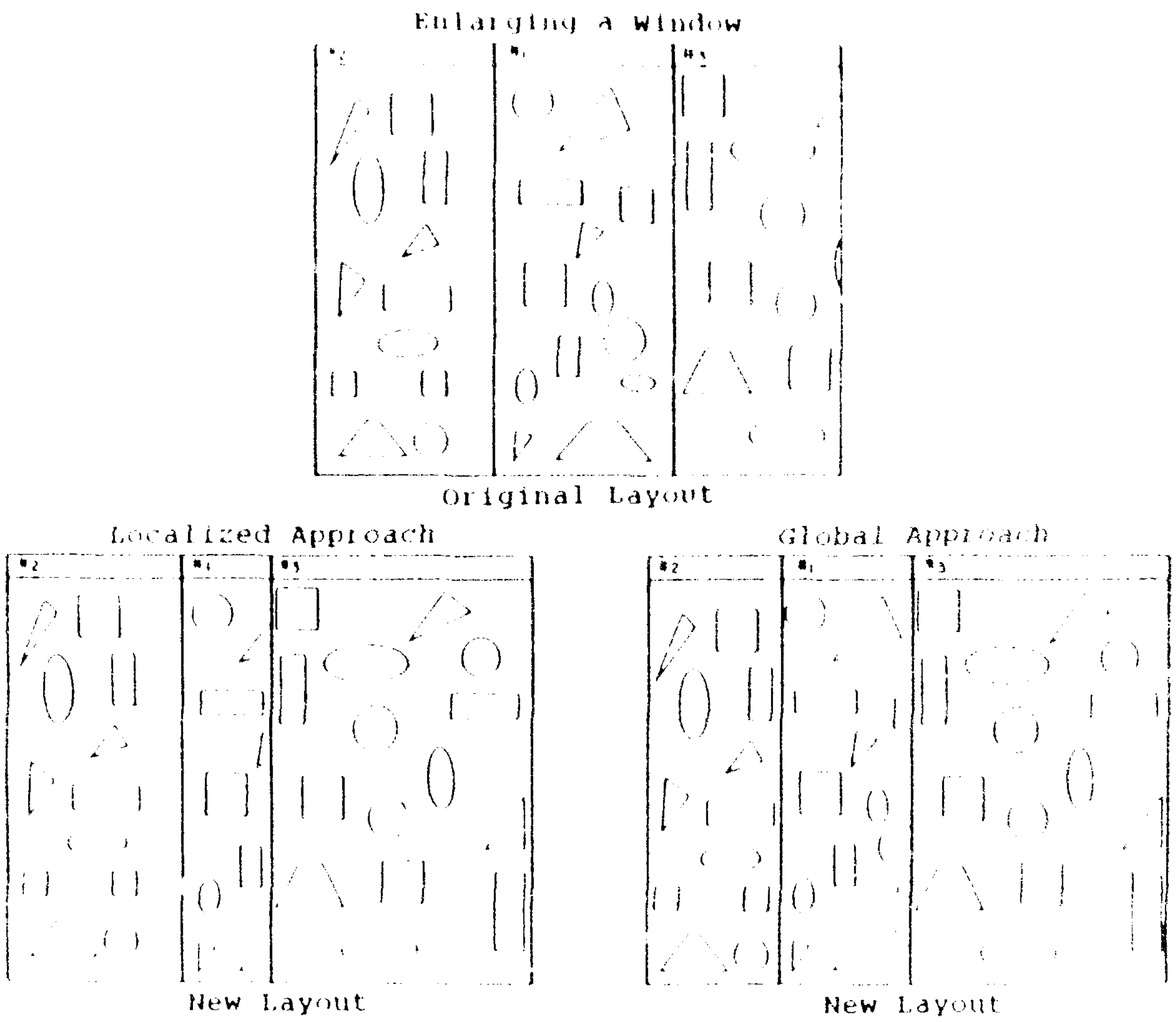


Figure B.[illegible] Localized Approach vs. Global Approach in Enlarging a Window

to open windows. The software [illegible] existing windows when opening [illegible] reduces the amount of space [illegible] specified minimum.

Experimental Task

The task environment consists of a number of data sets. Each window can accommodate a data set. Each data set contains a variety of two-dimensional objects (i.e., circles, ellipses, squares, rectangles, parallelograms, and trapezoids). You are asked to answer some questions about the contents of these data sets using the window management system. Please try to answer these questions as quickly as possible while minimizing incorrect answers.

Measures

Response accuracy, number of window management operations (i.e., openings, enlargings, and reopenings), and task completion time will be recorded. Task completion time will be divided into the following:

1. Window Management Time: This includes any time you spend arranging the display screen into a configuration that is suitable to complete the subtask. Screen arrangement time itself will be subdivided into the following components.

   Opening Time--this includes time you spend opening windows.

   Enlarging Time--this includes time you spend enlarging windows.

   Reopening Time--this includes time you spend reopening windows.

2. Task Solution Time: This measures the time you devote to determining the specific facts requested once you have completed opening and enlarging of the relevant windows.

You will be asked to complete a subjective rating scale questionnaire at the completion of each task block. A final questionnaire will also be administered at the end of the study.

[illegible]

Two window management systems employing the [illegible] and global approaches, respectively, will be used in this study. You will be asked to use these two window management systems to complete the following eight task blocks:

1. localized approach, low data set size variability, and low data set interdependency;

2. localized approach, low data set size variability, and high data set interdependency;

3. localized approach, high data set size variability, and low data set interdependency;

4. localized approach, high data set size variability, and high data set interdependency;

5. global approach, low data set size variability, and low data set interdependency;

6. global approach, low data set size variability, and high data set interdependency;

7. global approach, high data set size variability, and low data set interdependency;

8. global approach, high data set size variability, and high data set interdependency.

The order of these eight blocks will be different for different participants. Each of these eight task blocks requires you to extract information contained in 20 data sets to answer 36 questions.

Before each of the eight task blocks, a training session will be provided. Each block of the study will require about fifty minutes to complete. Brief rest breaks will be provided between blocks. The entire experiment will require about seven hours to complete, including administration of instructions, rest breaks, and completion of the rating scale questionnaire.

[illegible]

[illegible]

These demos have been [illegible] window management systems used [illegible] general demonstration. There is no difference between [illegible] approaches to window management in this demonstration. The window management system used in the second demonstration employs the [illegible] approach, while the window management system used in the third demonstration employs the global approach.

Demo 1: please type demo1 and press ENTER

You are asked to enter your code number to start the demo. You must enter the code number that I gave you and hit the ENTER key to start the demo.

You can see that there are a series of small rectangles, each containing a different character, shown at the top left corner of the left hand side display titled "DATA MENU". These small rectangles represent the data sets; at present you cannot see the contents of these data sets. The character inside each small rectangle represents a data set identifier. If you look at the text shown on the right hand side display, you can see the main command menu and question 1. This command menu reminds you how to use the four window management commands available to you. Question 1 asks you to answer the question "What is the total number of rectangles contained in data sets h and d?" Since you cannot see the contents of data sets h and d, you must open windows for these two data sets to answer this question. To open a window for data [illegible] will see [illegible] the left hand side [illegible] the ENTER [illegible]

[illegible] shown in the right hand side display. [illegible] display [illegible] can see an arrow [illegible] small rectangle. Hit the right [illegible] key [illegible]. The arrow [illegible] will move to the middle of the next small rectangle [illegible] character b. Now hit the ENTER key and you will see the small rectangle containing character b has become a big rectangle. The contents of data set b are shown in this big rectangle, called a window. Hit [illegible] and ENTER again. Now move the arrow cursor by hitting the right [illegible] key twice to the small rectangle containing character d. Hit ENTER [illegible] and the small rectangle containing character d will become a big rectangle (window d). It can be seen in the second row (window b) is shown in the first row. To answer the question, you have to count the total number of rectangles contained in data sets b and d. When you are ready to enter your answer, hit "a" and ENTER. The instruction "GIVE YOUR ANSWER" will then appear on the right hand side display. The answer to this question turns out to be 6. Type 6 and ENTER. You will be given the feedback "This answer is correct, enter any key to continue". If the answer you gave had been incorrect, the feedback would have been "This answer is incorrect. The correct answer is 6. Hit any key to continue". In either case, the system will continue to the next question when you hit any key as instructed. Now hit any key to continue.

The second question is " What is the difference between the total number of circles contained in data set b and the total number of trapezoids contained in data set r ". Since data set [illegible] trapezoids contained in data set r cannot be seen [illegible] window for data set r. [illegible] a window [illegible]

[illegible] and ENTER [illegible] suppose that [illegible] and then hit the ENTER key. You would then hear a "beep." Try it. Whenever you type an invalid command and hit ENTER, a beep will sound to indicate that you have made a typing mistake. Now hit 'o' and ENTER correctly. Use the right direction key to move the arrow cursor to the small rectangle containing character r and hit ENTER. This time you may be surprised to see that the small rectangle does not become a big rectangle. Instead an arrow cursor appears at the left boundary of the first window in the first row (window b). If you look at the right hand side display, you can see the new instruction "USE THE DIRECTION KEY TO CHOOSE A POSITION". You haven't done anything wrong. After two windows have been opened, you have to specify the position for any additional windows you want to open. You specify a position for the new window by placing the arrow cursor on the extreme left boundary of a row, the extreme right boundary of a row, or between two opened windows in a row. If you hit ENTER now, you will see that window r is placed on the left hand side of window b and the size of window b is reduced (since window b gives some of its space to window r). Count the requested graphic objects and hit 'a' to give your answer.

<u>Demo 2</u> (please type demo2 and press ENTER)

Enter your code number and hit the ENTER key to start the demo.

You can see there are already eleven open windows on the display. In these windows, the contents of some of the data sets are fully visible, while the contents of other data sets are partly visible. You can tell whether the contents of a data set are fully visible by looking for an asterisk '*' in the upper right corner of the window. If there is an asterisk displayed, the full contents of that data set are visible in

the window. Now look at the question on the right hand side display. The question requires you to count and enter the total number of squares in data sets e and g. Since you cannot view the full contents of either data set e or data set g, you will have to enlarge their windows.

To enlarge window e, first hit 'e' (for "enlarge") and ENTER. On the right hand side display you can see the new instruction "USE DIRECTION KEYS TO CHOOSE THE WINDOW WHICH YOU WANT TO ENLARGE". If you look at the left hand side display, you can see a cross cursor in the middle of the first window in row one (window k). Hit the right direction key four times. This moves the cross cursor to the middle of window e. Hit the ENTER key. You will now see the new instruction "USE LEFT OR RIGHT DIRECTION KEY TO ENLARGE THE WINDOW" on the right hand side display. The cross cursor automatically moves to the left boundary of window e (since there are no windows on the right hand side of window e, window e can only be enlarged towards the left). Now hit the left direction key ten times. Then hit ENTER. You can see that window e is enlarged, but the contents within it are still not fully displayed, while the size of window o is reduced (since it gave up some of its space to window e). You will have to enlarge window e further (following the same procedure). This time, when you enlarge window e, hit the left direction key five times. You can see from the asterisk that the full contents of data set e are now displayed. Since we have to get information from windows e and g, we will have to enlarge window g as well. Hit 'e' (for "enlarge") and ENTER. Then hit the down direction key once. Now hit the right direction key three times. The cross cursor should now be in the middle of window f. If you hit the ENTER key now, the system will allow you to enlarge window f (try it). The

cross cursor stays in the middle of window f. Since there are windows on both sides of window f, the system allows you to enlarge window f by moving the cross cursor towards either side. The system now asks you to use the left or right direction key to enlarge window f (look at the new instruction shown on the right hand side display). But wait! You do not want to enlarge window f! We are supposed to enlarge window g! You can hit the ESC key to respecify the window which you want to enlarge (try it and look at the new instruction on the right hand side display). The new instruction on the right hand side display asks you to "USE DIRECTION KEYS TO CHOOSE THE WINDOW WHICH YOU WANT TO ENLARGE". Hit the down direction key once and hit the right direction key four times. The cross cursor should now be in the middle of window g. Hit ENTER. The cross cursor will stay in the middle of window g. Hit the left direction key 14 times. Then hit ENTER. You can now view the full contents of data set g. But notice that window f has been closed and data set f has been hidden (data set f now appears as a small rectangle in the second row of small rectangles titled "HIDDEN DATA SETS" in the top left corner of the display.) A window will be closed automatically when it is fully covered by another window. This happens when the space left for the window is very small. Now, since you can view the full contents of data sets e and g, you can count the specified graphic objects and answer the question.

We will now proceed to the next question. Question 14 asks you "What is the total number of parallelograms contained in data sets f and p?" Since a window for data set p hasn't yet been opened, you will have to open it. Follow the procedure to open a window and put window p between windows g and h. Window p will be opened, but you will not be

able to view the full contents of data set p. There is an asterisk (*) in the upper right corner of window p. When we opened window p between windows g and h, window g and h had to give up space for the new window. As a result, the sizes of windows g and h were reduced. Window h was so small after giving up space, that it was automatically closed. Data set h now appears as a small rectangle in the second row of small rectangles in the top left corner of the display. Since you cannot view the full contents of window p, you will have to enlarge window p. Use the enlarging procedure to do this. After enlarging window p, you will also have to reopen window f to answer the question. Window f was opened earlier, but was automatically closed when we enlarged window g. To make space for a window that was opened, but later closed, we reopen the window, rather than open it. To reopen window f, hit 'r' and then hit ENTER. An arrow cursor is now shown in the first small rectangle of the second row at the top of the display. Hit the right direction key once. The arrow cursor moves to the small rectangle containing character f. Hit the ENTER key. The arrow cursor is now shown at the left boundary of window k. Now hit the right direction key five times. The arrow cursor moves to the right boundary of window row one (on the right hand side of window e). Now hit ENTER. The size of window e is reduced to make space for window f. Window f is now reopened. Since you cannot view the full contents of window f, you will have to enlarge it. After you have enlarged window f, count the specified graphic objects, hit 'a' and give your answer.

[illegible] please type 'demo' and press ENTER

Enter your code number and hit the ENTER key to start the demo.

You can see there are already eleven open windows on the display. In these windows, the contents of some of the data sets are fully visible, while the contents of other data sets are partly visible. Now look at the question on the right hand side display. The question requires you to count and enter the total number of squares in data sets e and g. Since you cannot view the full contents of either data set e or data set g, you will have to enlarge their windows.

To enlarge window e, first hit 'e' (for "enlarge") and ENTER. On the right hand side display you can see the new instruction "USE DIRECTION KEYS TO CHOOSE THE WINDOW WHICH YOU WANT TO ENLARGE". If you look at the left hand side display, you can see a cross cursor in the middle of the first window in row one (window k). Hit the right direction key four times. This moves the cross cursor to the middle of window e. Hit the ENTER key. You will now see the new instruction "USE LEFT OR RIGHT DIRECTION KEY TO ENLARGE THE WINDOW" on the right hand side display. The cross cursor automatically moves to the left boundary of window e. Now hit the left direction key ten times. Then hit ENTER. You can see that window e is enlarged, but the contents within it are still not fully displayed, while the sizes of the other windows in the same row are reduced (since they gave up some of their space to window e). You will have to enlarge window e further. This time, when you enlarge window e, hit the left direction key five times. You can see from the asterisk that the full contents of data set e are now displayed. Since we have to get information from windows e and g, we will have to enlarge window g as well. Hit 'e' (for "enlarge") and ENTER

Then hit the down direction key [illegible] four times. The cross cursor should now be in the middle of window g and hit ENTER. The cross cursor will stay in the middle of window g. Hit the left direction key 14 times. Then hit ENTER. You can now view the full contents of data set g. But notice that window h has been closed and data set h has been hidden. Now, since you can view the full contents of data sets e and g, you can count the specified graphic objects and answer the question.

Question 14 asks you "What is the total number of parallelograms contained in data sets n and p". Since a window for data set p hasn't yet been opened, you will have to open it. Follow the procedure to open a window and put window p between windows g and h. Window p will be opened, but you will not be able to view the full contents of data set p. When we opened window p in row two, all the other windows in row two had to give up space for the newly opened window. As a result, window h was so small after giving up space, that it was automatically closed. Data set h now appears as a small rectangle in the second row of small rectangles in the top left corner of the display. Since you cannot view the full contents of window p, you will have to enlarge window p. Use the enlarging procedure to do this. After enlarging window p, you will also have to reopen window n to answer the question. To reopen window n, hit 'r' and then hit ENTER. An arrow cursor is now shown in the first small rectangle of the second row at the top of the display. Hit the right direction key once. The arrow cursor moves to the small rectangle containing character n. Hit the ENTER key. The arrow cursor is now shown at the left boundary of window k. Now hit the right direction key five times. The arrow cursor moves to the right boundary of window

row one, on the right hand side of window e. Now hit ENTER. The sizes of all the other windows in this row are reduced to make space for window n. Window n is now reopened. Since you cannot view the full contents of window n, you will have to enlarge it. After you have enlarged window n, count the specified graphic objects, hit 'a', and give your answer.

NOTES:

1. You can use the backspace key to correct your input before you hit the ENTER key.

2. The ESC key can be very useful when you type a command and enter it, but then change your mind. Hitting the ESC key at this point will "undo" the last command you entered and bring the system back to where it was before you entered that command. But there are four exceptions about the ESC key:

   a. You cannot "undo" the answer you gave.

   b. You cannot "undo" a window that has been opened.

   c. You cannot "undo" a window that has been enlarged.

   d. You cannot "undo" a window that has been reopened.

Appendix D

Questionnaire

1. Was the localized approach to window management easy to learn

1	2	3	4	5
very easy		moderately easy		very difficult

2. Was the global approach to window management easy to learn

1	2	3	4	5
very easy		moderately easy		very difficult

3. localized approach, low data set size variability, and and low data set interdependency.

3a When the data set sizes are low variability, the data sets are low interdependency, and the screen hasn't yet been filled with data sets, how satisfied are you with the localized approach to window management ?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

3b When the data set sizes are low variability, the data sets are low interdependency, and the screen has been filled with data sets, how satisfied are you with the localized approach to window management ?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

3c When the data set sizes are low variability, the data sets are low interdependency, how satisfied are you with the localized approach to window management ?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

4. localized approach, low data set size variability, and high data set interdependency.

4a. When the data set sizes are low variability, the data sets are high interdependency, and the screen hasn't yet been filled with data sets, how satisfied are you with the localized approach to window management?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

4b. When the data set sizes are low variability, the data sets are high interdependency, and the screen has been filled with data sets, how satisfied are you with the localized approach to window management?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

4c. When the data set sizes are low variability, the data sets are high interdependency, how satisfied are you with the localized approach to window management?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

5. (localized approach, high data set size variability, and and low data set interdependency)

5a. When the data set sizes are high variability, the data sets are low interdependency, and the screen hasn't yet been filled with data sets, how satisfied are you with the localized approach to window management?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

5b. When the data set sizes are high variability, the data sets are low interdependency, and the screen has been filled with data sets, how satisfied are you with the localized approach to window management?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

5c. When the data set sizes are high variability, the data sets are low interdependency, how satisfied are you with the localized approach to window management?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

6. localized approach (high data set size variability and high data set interdependency)

6a. When the data set sizes are high variability, the data sets are high interdependency, and the screen hasn't yet been filled with data sets, how satisfied are you with the localized approach to window management?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

6b. When the data set sizes are high variability, the data sets are high interdependency, and the screen has been filled with data sets, how satisfied are you with the localized approach to window management?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

6c. When the data set sizes are high variability, the data sets are high interdependency, how satisfied are you with the localized approach to window management?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

7. global approach (low data set size variability, and low data set interdependency)

7a. When the data set sizes are low variability, the data sets are low interdependency, and the screen hasn't yet been filled with data sets, how satisfied are you with the global approach to window management?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

7b. When the data set sizes are low variability, the data sets are low interdependency, and the screen has been filled with data sets, how satisfied are you with the global approach to window management?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

7c When the data set sizes are low variability, the data sets are low interdependency, how satisfied are you with the global approach to window management ?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

8 (global approach, low data set size variability, and high data set interdependency)

8a When the data set sizes are low variability, the data sets are high interdependency, and the screen hasn't yet been filled with data sets, how satisfied are you with the global approach to window management ?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

8b When the data set sizes are low variability, the data sets are high interdependency, and the screen has been filled with data sets, how satisfied are you with the global approach to window management ?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

8c When the data set sizes are low variability, the data sets are high interdependency, how satisfied are you with the global approach to window management ?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

9 (global approach, high data set size variability, and low data set interdependency)

9a When the data set sizes are high variability, the data sets are low interdependency, and the screen hasn't yet been filled with data sets, how satisfied are you with the global approach to window management ?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

[illegible] When the data set sizes are high variability, the data sets are low interdependency, and the screen has been filled with data sets, how satisfied are you with the global approach to window management?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

[illegible] When the data set sizes are high variability, the data sets are low interdependency, how satisfied are you with the global approach to window management ?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

(global approach, high data set size variability, and high data set interdependency)

11a When the data set sizes are high variability, the data sets are high interdependency, and the screen hasn't yet been filled with data sets, how satisfied are you with the global approach to window management ?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

11b When the data set sizes are high variability, the data sets are high interdependency, and the screen has been filled with data sets, how satisfied are you with the global approach to window management ?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

11c When the data set sizes are high variability, the data sets are high interdependency, how satisfied are you with the global approach to window management ?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

[illegible]

[illegible]

[illegible]

How satisfied are you with the localized approach to window management?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

How satisfied are you with the global approach to window management?

1	2	3	4	5
extremely satisfied		just satisfied		not satisfied at all

Rank these two window management approaches in order of preference with 1 being more preferred and 2 less preferred.

Localized approach

Global approach

Low Interdependency [illegible]

Question 1
What is the difference between the total number of ellipses and rectangles contained in data set g and the total number of ellipses and rectangles contained in data set k?

Question 2
What is the total number of circles and squares contained in data sets g and k?

Question 3
What is the difference between the total number of ellipses and circles contained in data set [illegible] and the total number of trapezoids and parallelograms contained in data set g?

Question 4
What is the total number of rectangles and trapezoids contained in data sets g and k?

Question 5
What is the difference between the total number of squares and rectangles contained in data set s and the total number of trapezoids and ellipses contained in data set e?

Question 6
What is the difference between the total number of circles and parallelograms contained in data set g and the total number of circles and parallelograms contained in data set k?

Question 7
What is the difference between the total number of ellipses and rectangles contained in data set [illegible] and the total number of circles and parallelograms contained in data set e?

Question 8
What is the total number of circles and squares contained in data sets g and s?

Question 9
What is the difference between the total number of ellipses and squares contained in data set k and and the total number of ellipses and squares contained in data set [illegible]?

Question 10
What is the difference between the total number of trapezoids and parallelograms contained in data set [illegible] and the total number of ellipses and rectangles contained in data set e?

Question 11:

What is the difference between the total number of ellipses and rectangles contained in data set b and the total number of ellipses and rectangles contained in data set s?

Question 12:

What is the total number of rectangles and parallelograms contained in data sets g and t?

Question 13:

What is the difference between the total number of rectangles and trapezoids contained in data set k and the total number of rectangles and trapezoids contained in data set p?

Question 14:

What is the total number of parallelograms and squares contained in data sets e and j?

Question 15:

What is the difference between the total number of squares and circles contained in data set q and the total number of trapezoids and parallelograms contained in data set b?

Question 16:

What is the total number of circles and trapezoids contained in data sets g and s?

Question 17:

What is the difference between the total number of ellipses and squares contained in data set c and the total number of trapezoids and rectangles contained in data set [illegible]?

Question 18:

What is the difference between the total number of ellipses and squares contained in data set k and the total number of ellipses and squares contained in data set p?

Question 19:

What is the difference between the total number of ellipses and rectangles contained in data set h and the total number of ellipses and rectangles contained in data set n?

Question 20:

What is the total number of circles and squares contained in data sets e and j?

Question 21:

What is the difference between the total number of ellipses and circles contained in data set q and the total number of trapezoids and parallelograms contained in data set d?

Question 22:

What is the total number of rectangles and trapezoids contained in data sets b and s?

Question 23

What is the difference between the total number of squares and rectangles contained in data set i and the total number of trapezoids and ellipses contained in data set g?

Question 24

What is the difference between the total number of circles and parallelograms contained in data set c and the total number of circles and parallelograms contained in data set t?

Question 25

What is the difference between the total number of ellipses and rectangles contained in data set l and the total number of circles and parallelograms contained in data set p?

Question 26

What is the total number of circles and squares contained in data sets h and k?

Question 27

What is the difference between the total number of ellipses and squares contained in data set a and and the total number of ellipses and squares contained in data set r?

Question 28

What is the difference between the total number of trapezoids and parallelograms contained in data set j and the total number of ellipses and rectangles contained in data set e?

Question 29

What is the difference between the total number of ellipses and rectangles contained in data set m and the total number of ellipses and rectangles contained in data set q?

Question 30

What is the total number of rectangles and parallelograms contained in data sets d and s?

Question 31

What is the difference between the total number of rectangles and trapezoids contained in data set i and the total number of rectangles and trapezoids contained in data set r?

Question 32

What is the total number of parallelograms and squares contained in data sets b and g?

Question 33

What is the difference between the total number of squares and circles contained in data set c and the total number of trapezoids and parallelograms contained in data set f?

Question 34:
What is the total number of circles and trapezoids contained in data sets l and [illegible]?

Question 35:
What is the difference between the total number of ellipses and squares contained in data set p and the total number of trapezoids and rectangles contained in data set o?

Question 36:
What is the difference between the total number of ellipses and squares contained in data set h and the total number of ellipses and squares contained in data set k?

<u>High Interdependency Task</u>

Question 1:
What is the difference between the total number of ellipses and rectangles contained in data set e and the total number of ellipses and rectangles contained in data set j?

Question 2:
What is the difference between the total number of circles and squares contained in data set e and the total number of circles and squares contained in data set j?

Question 3:
What is the difference between the total number of ellipses and circles contained in data set p and the total number of trapezoids contained in data sets e and j?

Question 4:
What is the difference between the total number of rectangles and squares contained in data set p and the total number of parallelograms contained in data sets e and j?

Question 5:
What is the sum of the number of trapezoids contained in data set p, ellipses contained in data set j, circles contained in data set t, and rectangles contained in data set e?

Question 6:
What is the total number of parallelograms contained in data sets e, j, p, and t?

Question 7:
What is the sum of the number of ellipses contained in data set p rectangles contained in data set j, squares contained in data set q and trapezoids contained in data set t?

Question 8:
What is the difference between the total number of circles contained in data sets p and t and the total number of squares contained in data sets e and j?

Question 9:
What is the total number of rectangles contained in data sets k, p, q and t?

Question 10:
What is the sum of the number of squares contained in data set p, parallelograms contained in data set e, trapezoids contained in data set q, and ellipses contained in data set j?

Question 11:
What is the total number of circles contained in data sets c, e, i, and q?

Question 12:
What is the difference between the total number of trapezoids contained in data sets p and q and the total number of rectangles contained in data sets j and t?

Question 13:
What is the total number of squares contained in data sets c, e, i, and k?

Question 14:
What is the difference between the total number of rectangles contained in data sets p and q and the total number of trapezoids contained in data sets j and t?

Question 15:
What is the sum of the number of circles contained in data set e, squares contained in data set b, ellipses contained in data set c, and parallelograms contained in data set i?

Question 16:
What is the difference between the total number of trapezoids contained in data sets k and p and the total number of ellipses contained in data sets j and t?

Question 17:
What is the sum of the number of ellipses contained in data set e, circles contained in data set i, parallelograms contained in data set q, and squares contained in data set o?

Question 18:
What is the total number of circles contained in data sets b, c, j, and t?

Question 19:

What is the difference between the total number of ellipses and rectangles contained in data set f and the total number of ellipses and rectangles contained in data set r?

Question 20:

What is the difference between the total number of circles and squares contained in data set k and the total number of circles and squares contained in data set p?

Question 21:

What is the difference between the total number of ellipses and circles contained in data set a and the total number of trapezoids contained in data sets e and i?

Question 22:

What is the difference between the total number of rectangles and squares contained in data set q and the total number of parallelograms contained in data sets j and o?

Question 23:

What is the sum of the number of trapezoids contained in data set c, ellipses contained in data set t, circles contained in data set h, and rectangles contained in data set b?

Question 24:

What is the total number of parallelograms contained in data sets f, k, p, and r?

Question 25:

What is the sum of the number of ellipses contained in data set e, rectangles contained in data set m, squares contained in data set a, and trapezoids contained in data set i?

Question 26:

What is the difference between the total number of circles contained in data sets j and q and the total number of squares contained in data sets b and o?

Question 27:

What is the total number of rectangles contained in data sets c, d, n, and t?

Question 28:

What is the sum of the number of squares contained in data set f, parallelograms contained in data set k, trapezoids contained in data set r, and ellipses contained in data set p?

Question 29:

What is the total number of circles contained in data sets a, i, m, and n?

Question 30

What is the difference between the total number of trapezoids contained in data sets b and e and the total number of rectangles contained in data sets o and q?

Question 31

What is the total number of squares contained in data sets h, j, s, and t?

Question 32

What is the difference between the total number of rectangles contained in data sets f and k and the total number of trapezoids contained in data sets c and d?

Question 33

What is the sum of the number of squares contained in data set g, ellipses contained in data set m, circles contained in data set r, and parallelograms contained in data set p?

Question 34

What is the difference between the total number of trapezoids contained in data sets a and h and the total number of ellipses contained in data sets l and n?

Question 35

What is the sum of the number of ellipses contained in data set q, circles contained in data set [illegible], parallelograms contained in data set e, and squares contained in data set o?

Question 36

What is the total number of circles contained in data sets h, j, s, and t?

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